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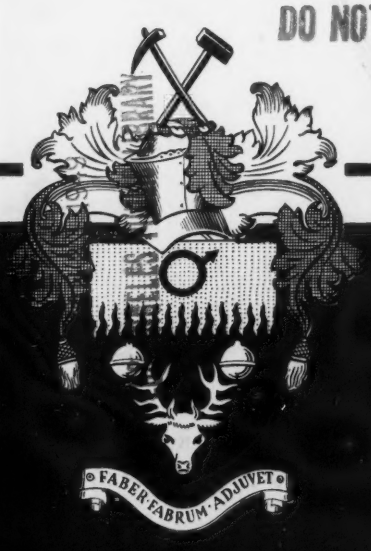

VOL. 160 PART 4

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CLEVELAND SPECIAL ALLOY GRAIN ROLLS ★

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Keynote of production at the Davy-United Roll Foundry is a systematic scientific control of all stages of manufacture.

In the moulding stage laboratory determinations decide the best types of moulding sands to be employed; influence the design of the mould itself and define the requisite drying temperatures and times by which successful castings may be ensured. In the melting stage similar determinations rule the selection of refractories and fuels, the composition of the charge and the melting process itself. The process of casting, the stage of cooling and the heat treatment which follows, are governed at every step by the same rigid control.

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A greatly improved Grain Roll, made by specialised methods both with regard to metal and manufacture. The alloys used include Nickel, Chrome and Molybdenum, blended to make a general purpose roll in which strength is combined with better wearing qualities. Due to the alloy content the structure is finer, giving a larger tonnage per Roll dressing than the standard type of Grain Roll. It has been very successfully used on most sections and has given particularly fine service for Flange Rails up to the largest sizes, special Sleepers and Sole Plates where sharp points or depressions on the section call for a superior type of metal to stand up to the work. The " Cleveland Special " Alloy Grain Roll shows great practical advantage over the ordinary type of Grain Roll for all finishing purposes and for many roughing purposes too.

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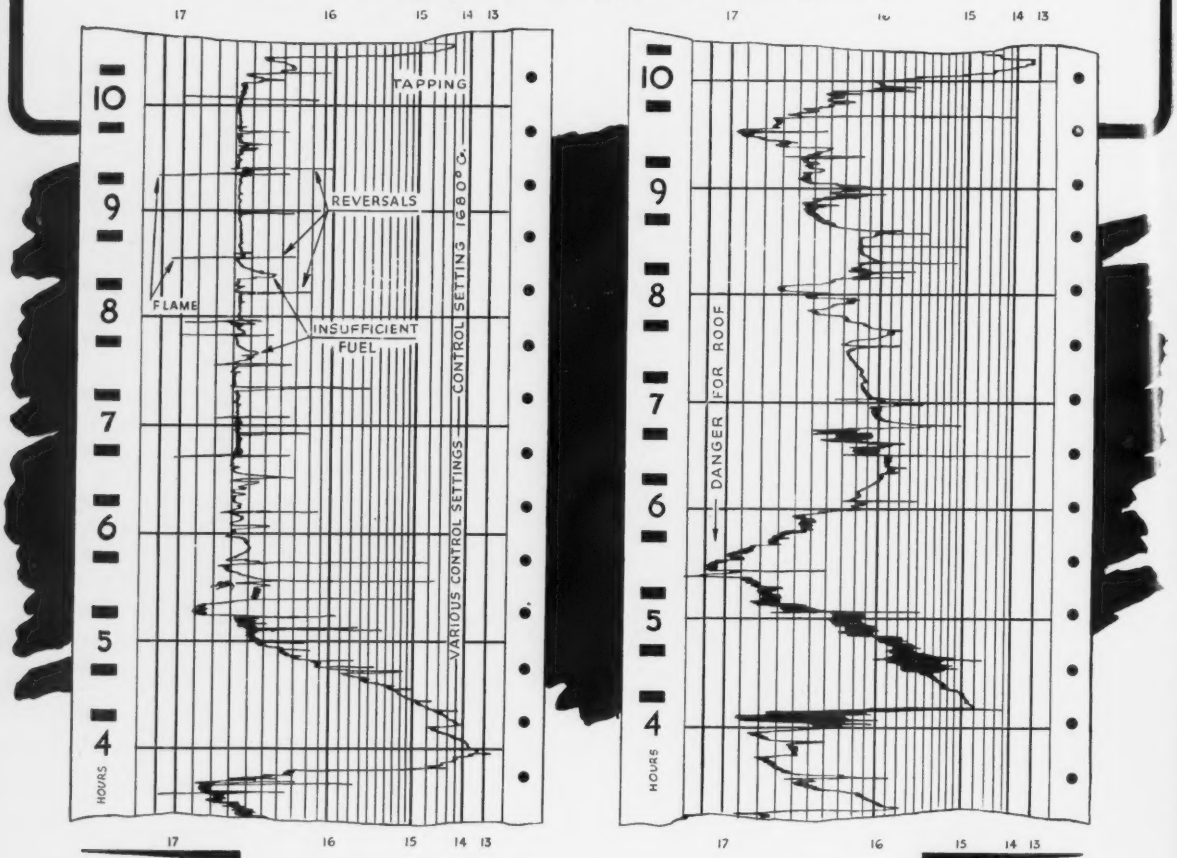
Specimen charts taken of a 50 ton Oilfired open-hearth furnace (charging and refining period). °Centigrade × 100.



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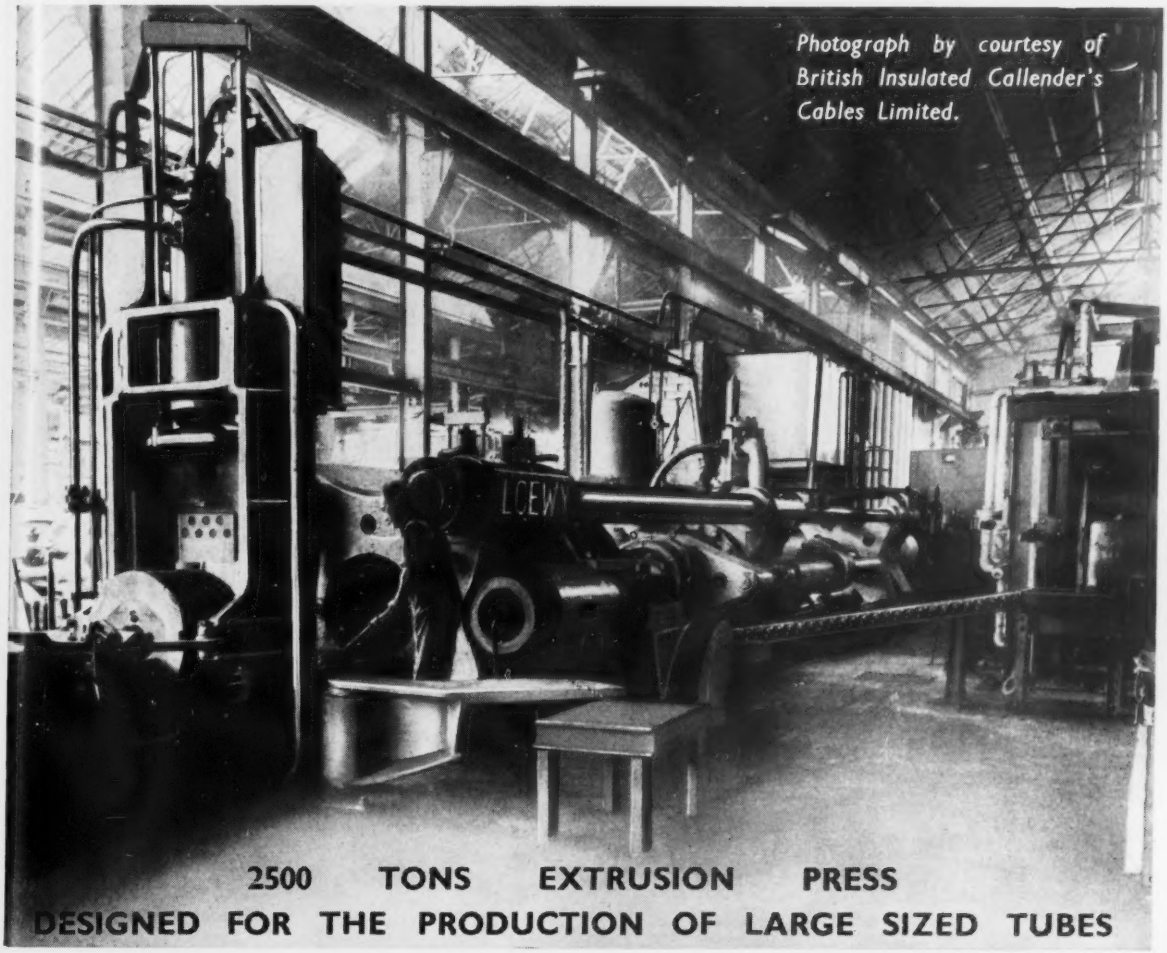

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These girls shivered in their shoes, but . . .

the gardener's crops grew hot and strong!

The frost never caught old Giles' superb runner beans outside the main workshop windows, but the feet and fingers of the girls working *inside* got well and truly nipped. So the welfare-minded management sent for the Ministry's Regional Fuel Engineer.

When he arrived, he found that the main supplying steam to heat the building was lagged on all *exposed* surfaces, but ran quite bare for 200 yards beneath old Giles' vegetable plot. No wonder the crops flourished and the girls shivered!

To-day the pipe is lagged for its whole length, the girls are warm and happy, output is soaring and gardener Giles is wondering how he can get soil-heating for his precious crops!

This case was perhaps typical of many wasteful practices that are still costing the nation thousands of tons of coal a year. All too often 'out of sight' means 'out of mind', and the leak of hard-won fuel continues year after year, unchallenged and unchecked.

You are a go-ahead type, of course, so your Fuel Efficiency is naturally of a high standard—but could there be *anything* you've overlooked? There's one way of making sure—ask the Ministry's Regional Fuel Engineer to visit you. His advice *may* be worth its weight in gold and his services are FREE.

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Northern	Government Buildings, Ponteland Road, Newcastle-on-Tyne, 5	Newcastle 28131
North-Eastern	Century House, South Parade, Leeds, 1	Leeds 30611
North-Eastern	Mount Pleasant School, Sharrow Lane, Sheffield	Sheffield 52461
North-Midland	Castle Gate House, Castle Gate, Nottingham	Nottingham 46216
Eastern	Shaftesbury Road, Brooklands Avenue, Cambridge	Cambridge 56268
London	Mill House, 87/89, Shaftesbury Avenue, W.1	Gerrard 9700
South-Eastern	Forest Road, Hawkenbury, Tunbridge Wells, Kent	Tun. Wells 2780
Southern	Whiteknights, Earley, Reading	Reading 61491
Wales	27, Newport Road, Cardiff	Cardiff 9234
South-Western	12/14, Apsley Road, Clifton, Bristol, 8	Bristol 38223
Midland	Temporary Office Buildings, Hagley Road West, Birmingham 17	Bearwood 3071
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Scotland	145, St. Vincent Street, Glasgow, C.2	Glasgow City 7633
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AND PUT TO WORK . . . .

The second battery — 17 W-D Becker Coke Ovens — has just been put to work at Worsborough for the Barnsley District Coking Company, Ltd.

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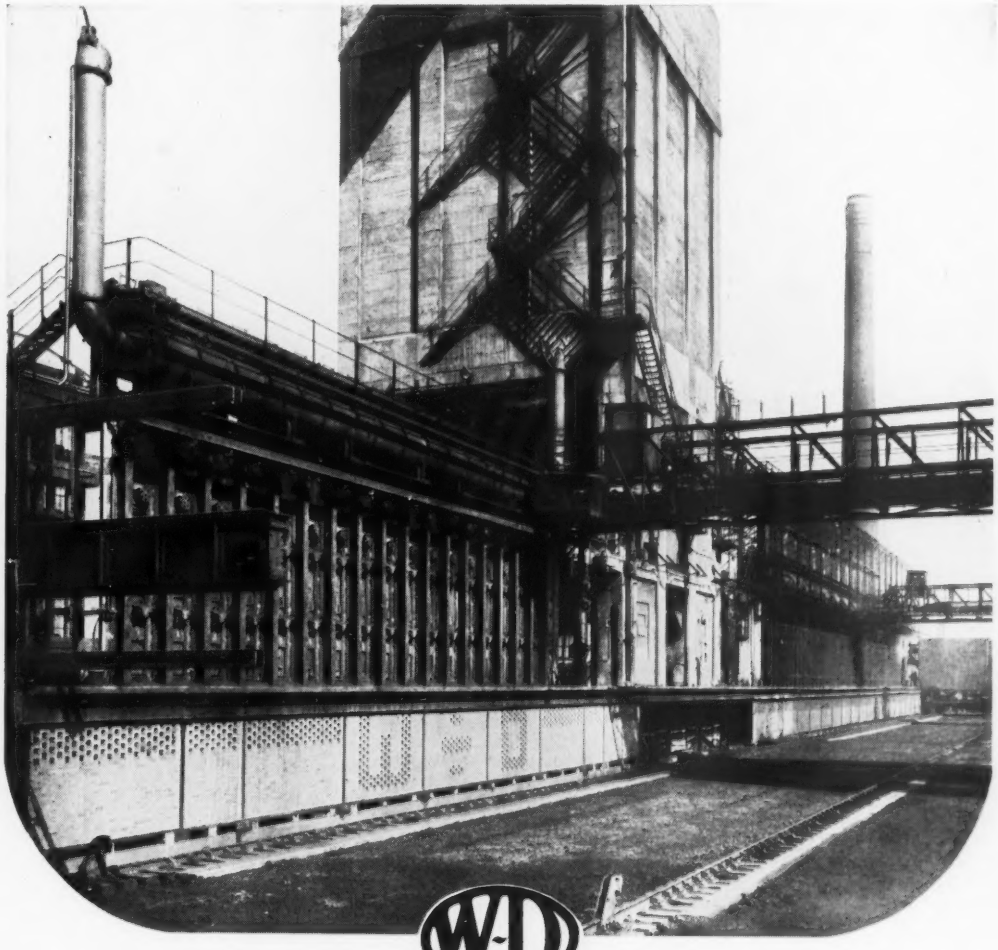
No other design of oven has ever been ordered where the W-D Becker Coke Oven has once been adopted.



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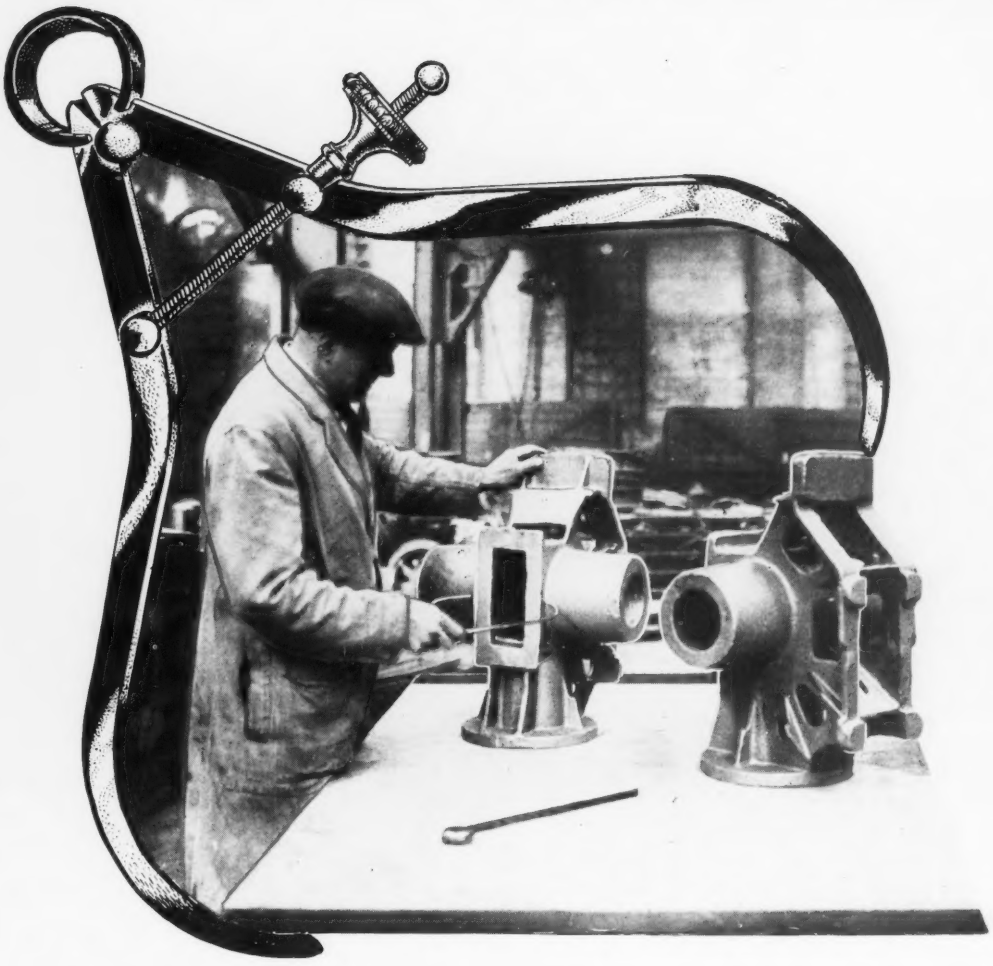

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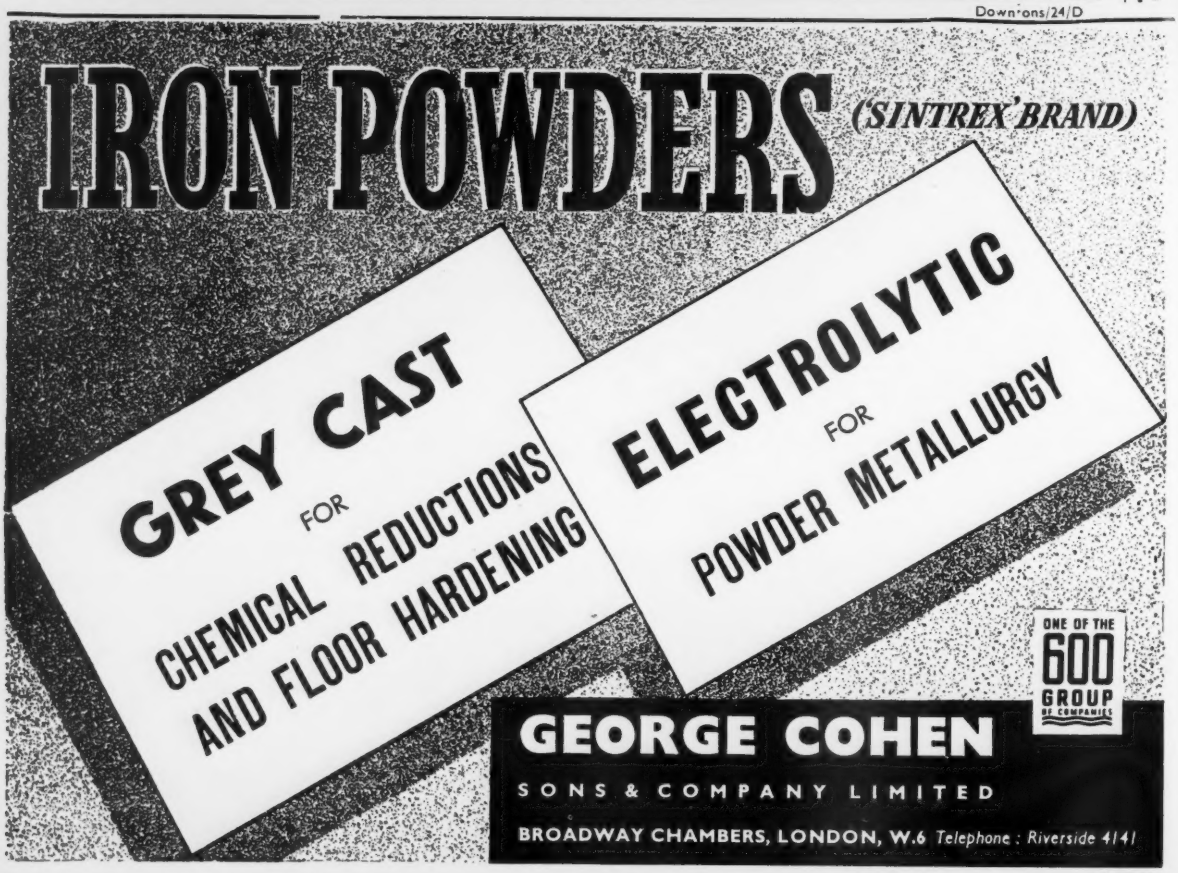

For metallurgist and engineer . . .

This 400pp. book describes the varied applications of Molybdenum as an alloying element in a wide range of materials. It presents the fundamentals which must guide the selection of the most suitable alloys for specific applications.

Much recent information is included, some of it hard to find elsewhere. About 500 references to technical literature facilitate further reading, and there are 187 diagrams and 91 tables.

The book is available free on request by responsible metallurgists and engineers and by students.

CONTENTS

Technical effects of Molybdenum in steel, steel castings and cast iron.
Fundamental effects of heat treatment on microstructures.
Addition of Molybdenum.
Alloy engineering steels—medium, low, high carbons; low temperature properties, machineability.
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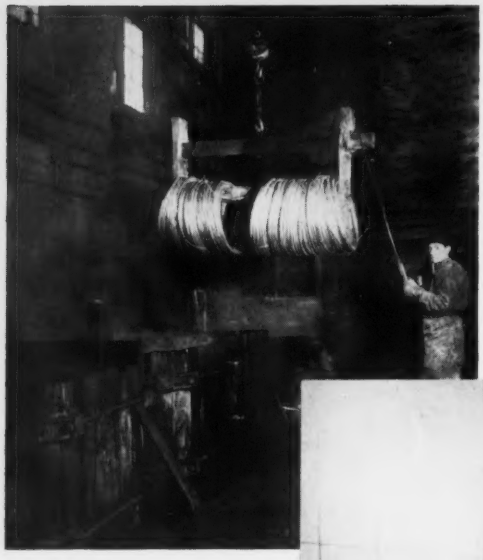
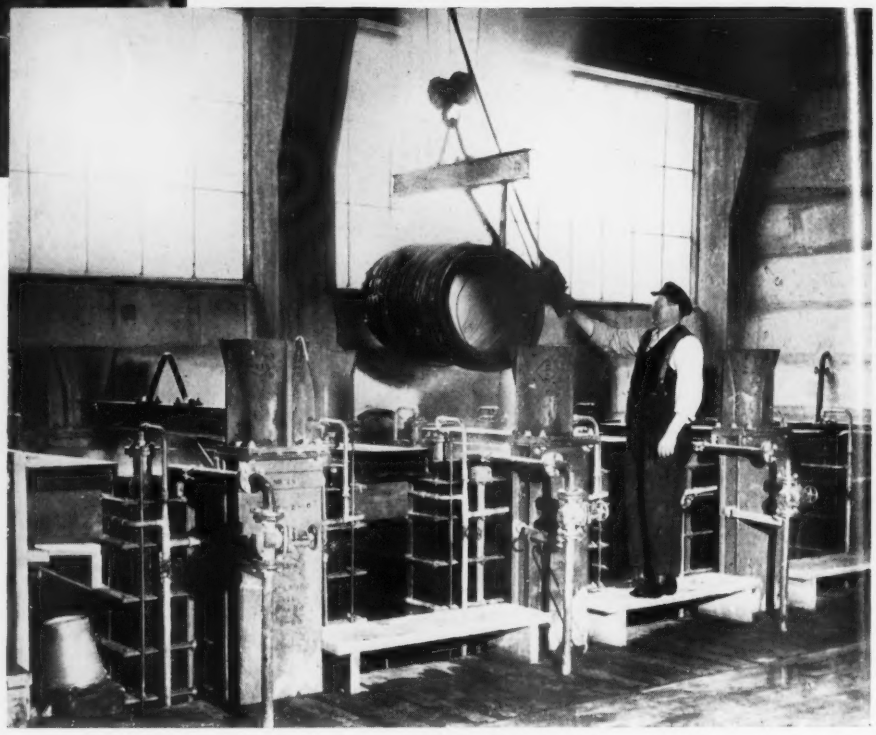


A *'before and after'* STORY FROM SWEDEN



BEFORE - *above*

The old plant meant clouds of acid fume from the tanks surrounding the operator.

AFTER - *right*

Fume rises only from the load as it comes from the new Kestner plant; the fume removal system keeping the tanks themselves clear and clean.

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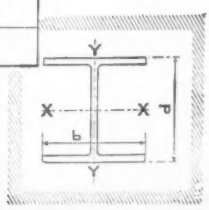
Size d x b inches	Wt. Lbs per Ft. = W	Area in sq. ins.	Web Ratio = Depth / Web	Thickness		Moment of Inertia - I		Modulus of Section - Z		Radius of Gyration - R.G.		$\frac{Z_{XX}}{Wt.\ (lbs.) \times Depth\ (ins.)} \times 1000$
				Web	Flange	X - X	Y - Y	X - X	Y - Y	X - X	Y - Y	
6 x 6	25	7·35	19·35	·31	·46	47·24	16·76	15·75	5·59	2·53	1·51	105·0
7 x 7	34	10·00	20·00	·35	·55	88·15	31·48	25·19	9·00	2·97	1·77	105·8
8 x 8	45	13·23	20·50	·39	·64	152·76	55·02	38·19	13·75	3·39	2·04	106·0
10 x 10	62·63	18·42	23·25	·43	·72	338·97	119·94	67·79	23·98	4·29	2·54	108·2
12 x 12	82·55	24·28	25·53	·47	·79	652·00	228·00	108·60	38·00	5·18	3·07	109·6
14 x 12	100	29·41	25·45	·55	·92	1048·40	265·20	149·80	44·21	5·97	3·00	107·0
16 x 12	110	32·35	29·10	·55	1·00	1504·60	285·30	188·10	48·05	6·82	2·99	106·8
18 x 12	122	35·88	30·50	·59	1·08	2094·50	311·40	232·70	51·90	7·64	2·95	106·0
20 x 12	135	39·71	31·746	·63	1·16	2808·00	334·60	280·80	55·78	8·41	2·90	104·0
22 x 12	150	44·12	33·84	·65	1·28	3768·00	368·70	342·50	61·46	9·24	2·89	103·8
24 x 12	165	48·53	34·28	·70	1·36	4857·00	393·20	396·40	65·53	9·90	2·85	100·1



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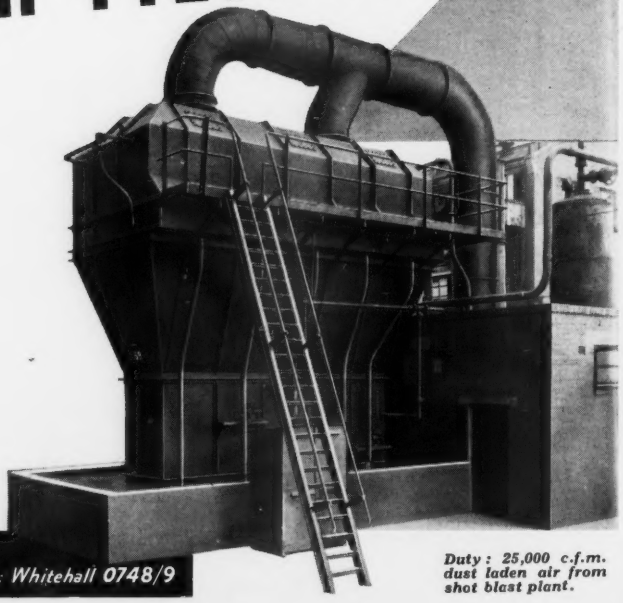

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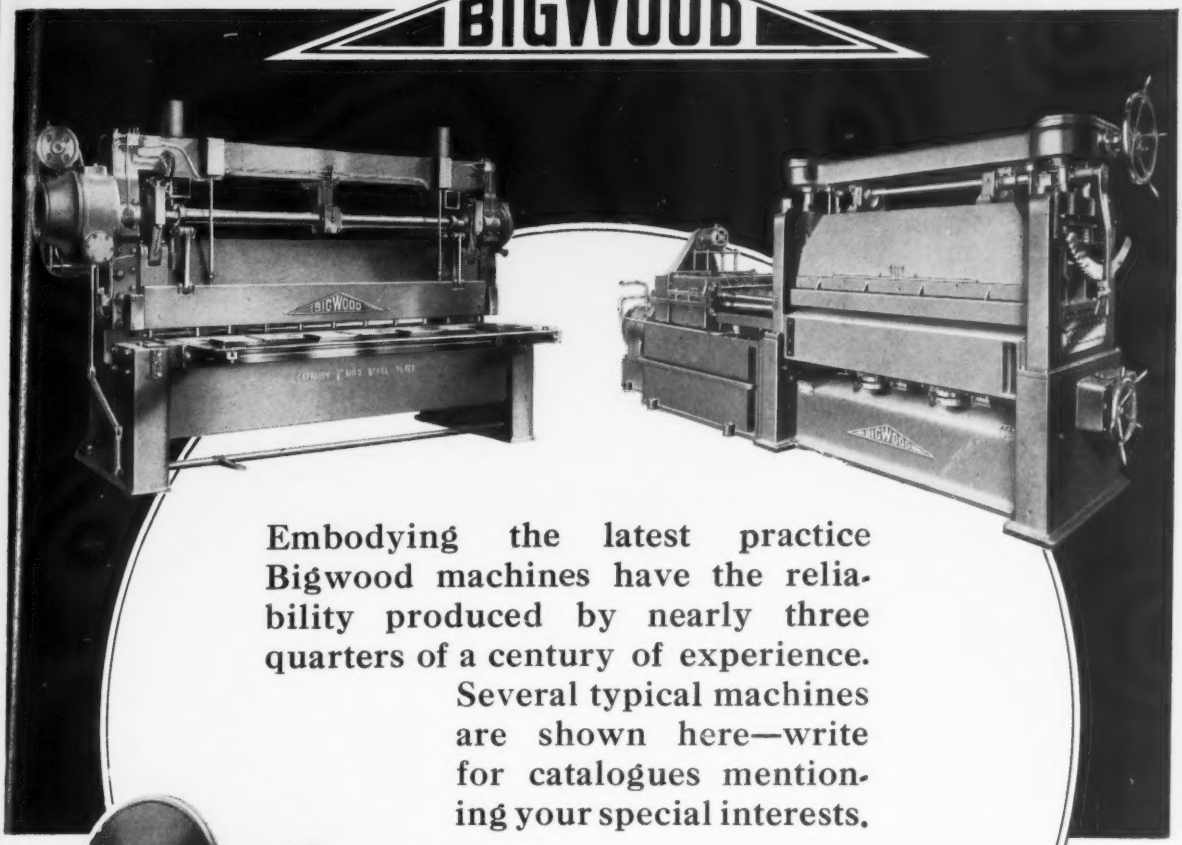
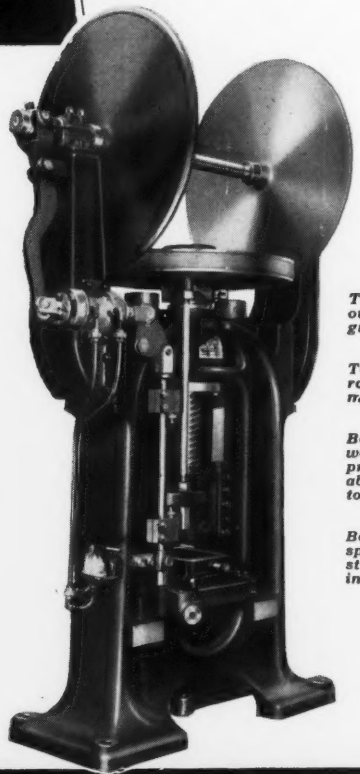


Embodying the latest practice Bigwood machines have the reliability produced by nearly three quarters of a century of experience. Several typical machines are shown here—write for catalogues mentioning your special interests.

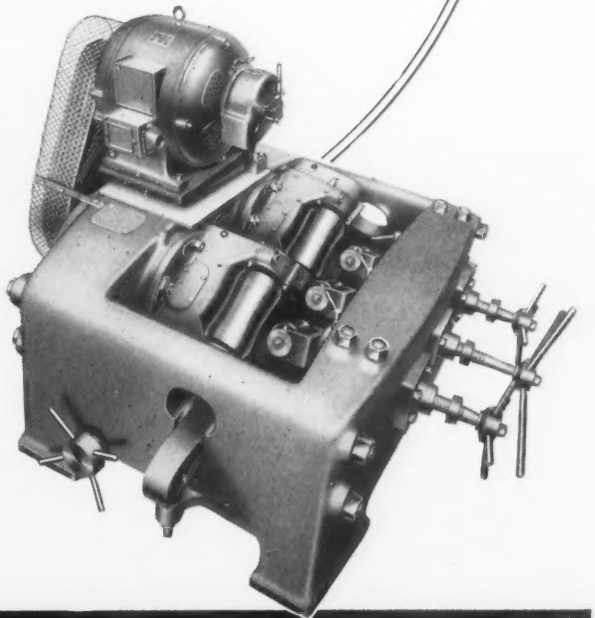


Top left:—Light type overcrank precision guillotine shear.

Top right:—Precision roller sheet levelling machine.

Bottom left:—Bigwood friction screw press—models available from 25 to 500 tons.

Bottom right:—High speed tube and bar straightening machine



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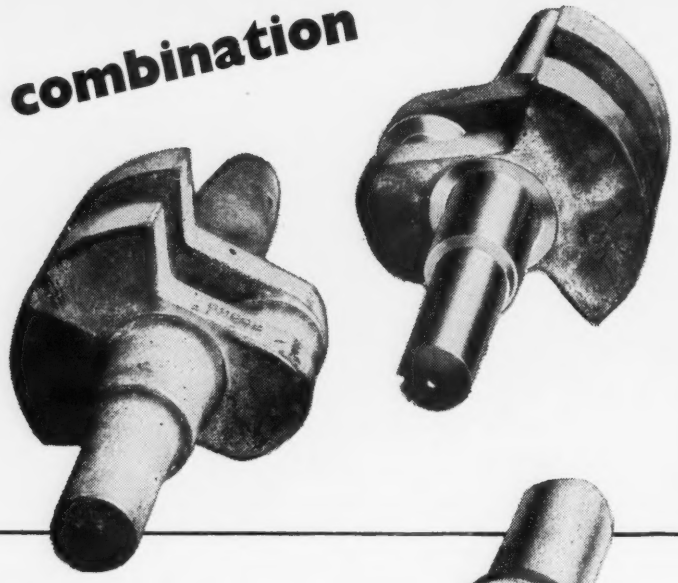
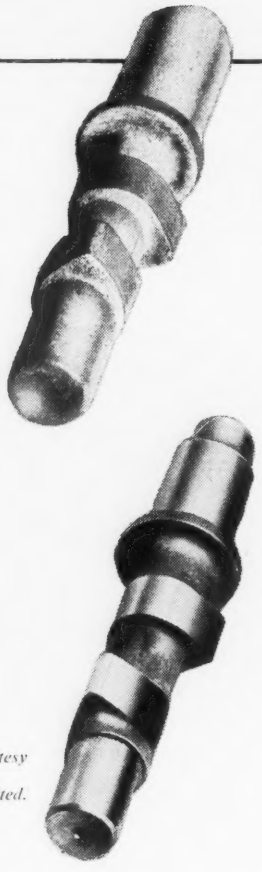


. . Acicular Cast Iron



These crankshafts, produced by Messrs. Douglas (Kingswood) Ltd., called for a cast iron with high strength, toughness, good resistance to wear and to shock. The nickel molybdenum cast iron specified is produced under British Patent No. 545102 and has given consistently the following mechanical properties: Maximum Stress — 25-32 tons per sq. inch; Impact Value (B.S.I. Cast Iron) — 25-32 ft. lb.; Hardness — 286-302 Brinell.

Founding presents no particular difficulty, no heat treatment is necessary and despite the high Brinell hardness number this material machines quite readily. The very satisfactory results obtained with this acicular cast iron have led to its application being extended to other items such as camshafts, wheel hubs and brake drums.

Crankshafts and Camshafts by courtesy of Messrs. Douglas (Kingswood) Limited.

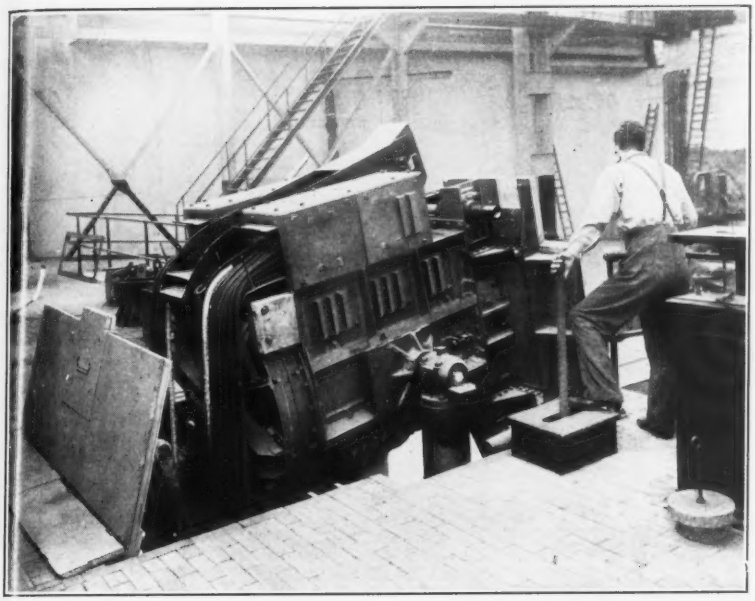
2/M/28

For further particulars write to:

The Mond Nickel Company Limited

Grosvenor House, Park Lane, London, W.1

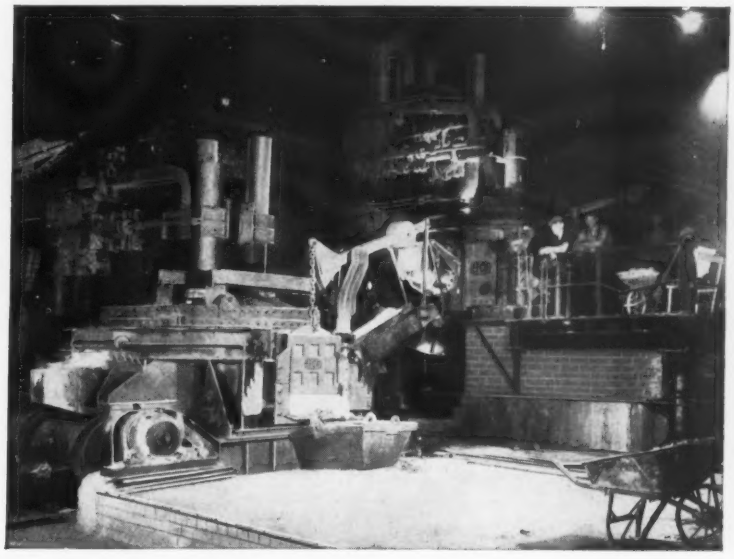
STEEL MELTING FURNACES



The illustration on the left shows a Large High Frequency Furnace with Steel Body incorporating special magnetic screen. Note perfect control with hydraulic operation.

The illustration below shows a Duplex Electric Melting Installation. Output 4 tons per hour.

EFCO supplied most of the Electric Melting Equipment in England during the war, including EFCO-Heroult Arc Furnaces, EFCO-Northrup High Frequency Induction Furnaces and Ajax-Wyatt Normal Frequency Furnaces for non-ferrous alloys.



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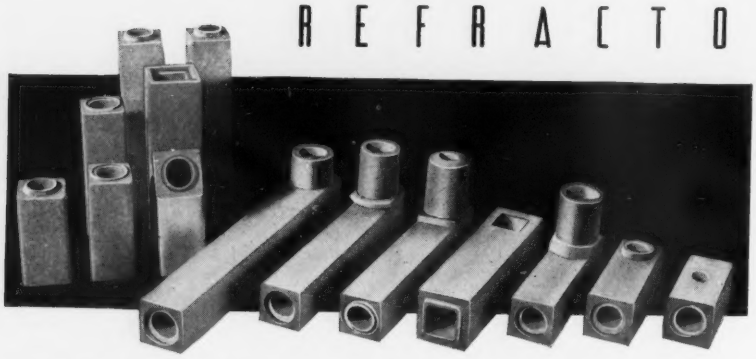

End and Through Runners form the radial legs from the centre or key brick of a bottom-casting assembly.

Characteristics of these highly important and intricate pieces of refractories for the uphill-cast are strength, accuracy of shape and dimensions, perfect joints, high spall resistance and a smooth unobstructed bore.

Experience for more than 25 years has shown us how to tackle the difficult problems in manufacturing and moulding these to the satisfaction of consumers.

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The potentiometer system (which measures Thermo-couple electromotive force in terms of temperature) is operated by five *electrically* connected units which eliminate mechanical linkages, chopper bars and constantly moving parts, while it ensures quick response to changing conditions. As there is no mechanical motion of any kind until a change of temperature occurs, the Pyromaster functions for long periods without wear or need for adjustment. No lubrication is required. Ingeniously simplified construction affords remarkable reliability and ready accessibility to parts. Temperature ranges extend to 2,150° C.

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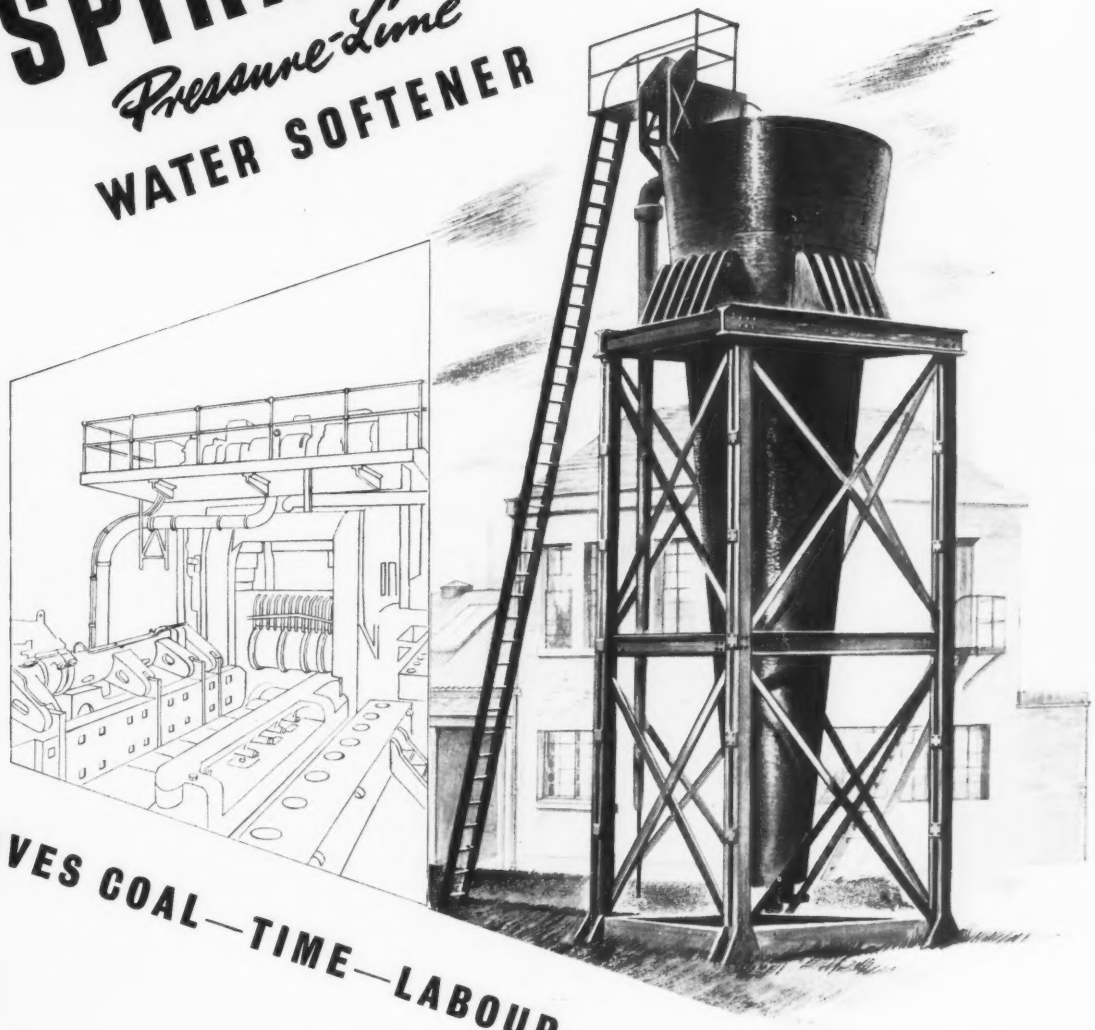

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- The latest method of softening boiler feed water.
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- Removes calcium temporary hardness in five minutes.
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- No moving parts, no pumping.
- Residual hardness is removed by a Permutit Fully Automatic Base Exchange Softener.

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INCORPORATING

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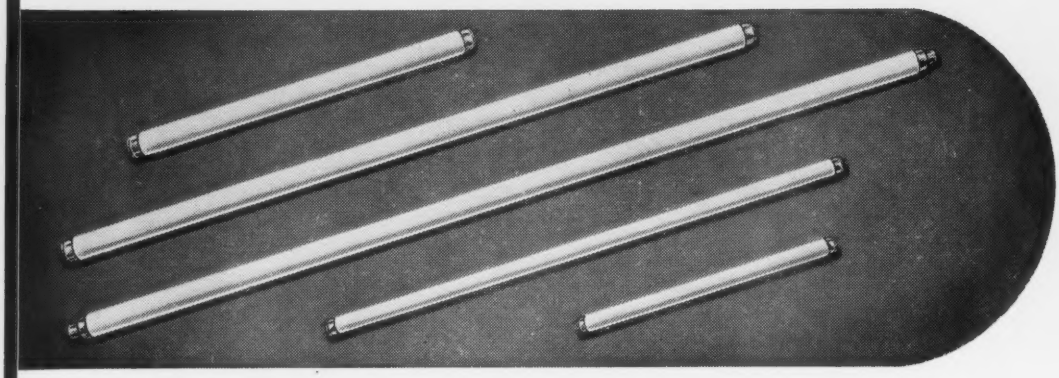

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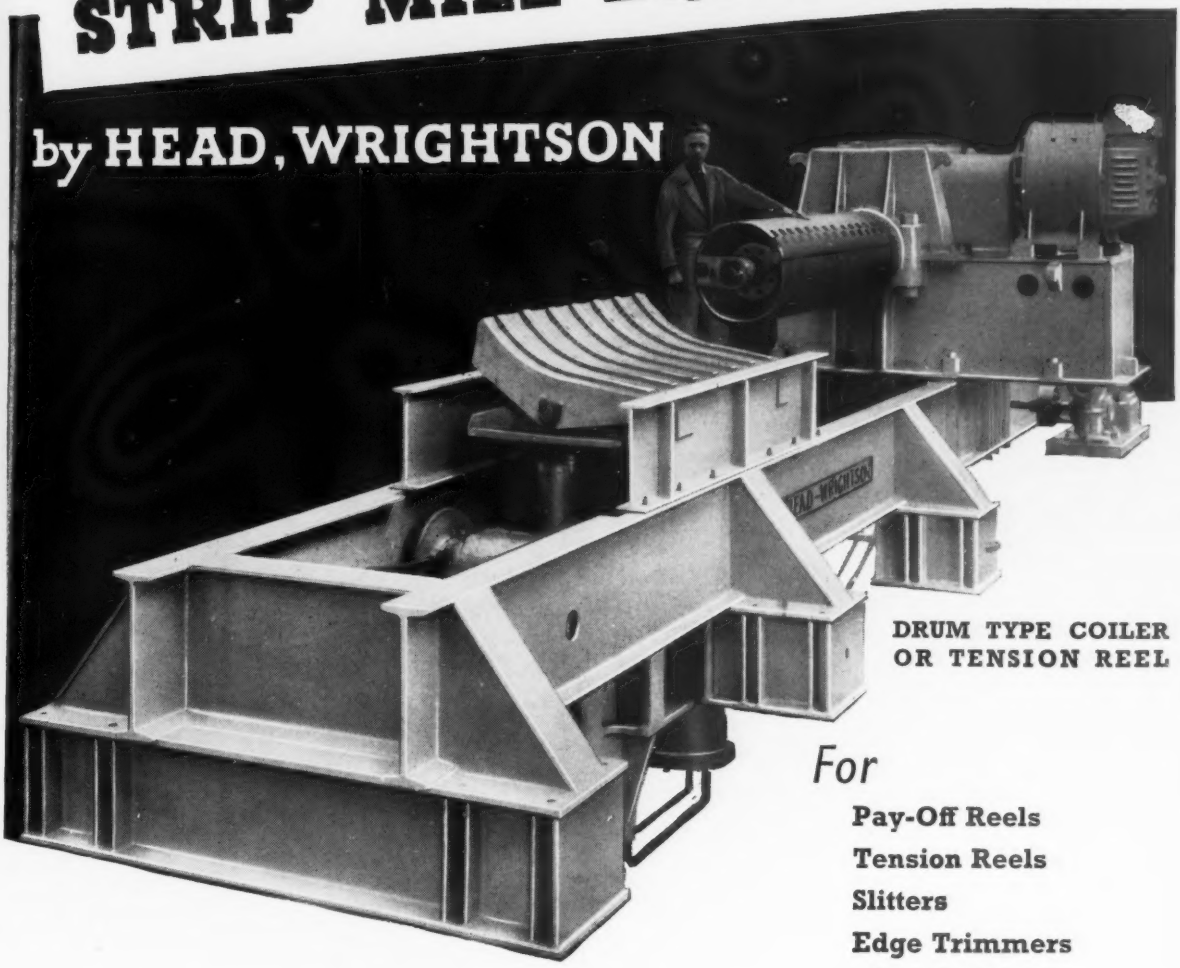
by HEAD, WRIGHTSON



DRUM TYPE COILER
OR TENSION REEL

The unit illustrated is a Tension Coiler designed and built by Head Wrightson as part of a line recently installed for uncoiling, levelling, slitting and re-coiling of cold rolled steel strip up to 10 tons weight. A coil carriage is provided for the handling of the coils and has an automatic discharge feature.

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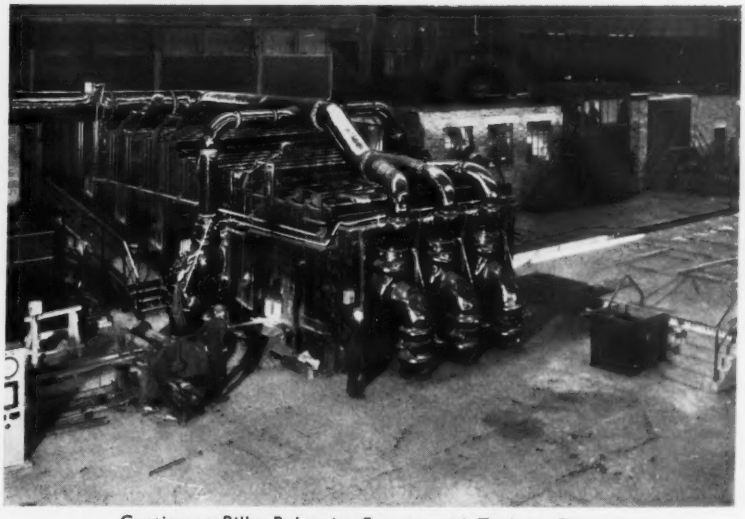

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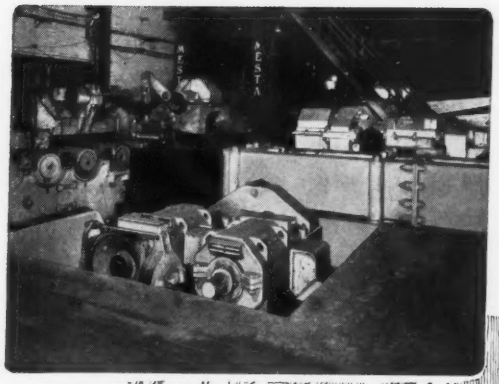

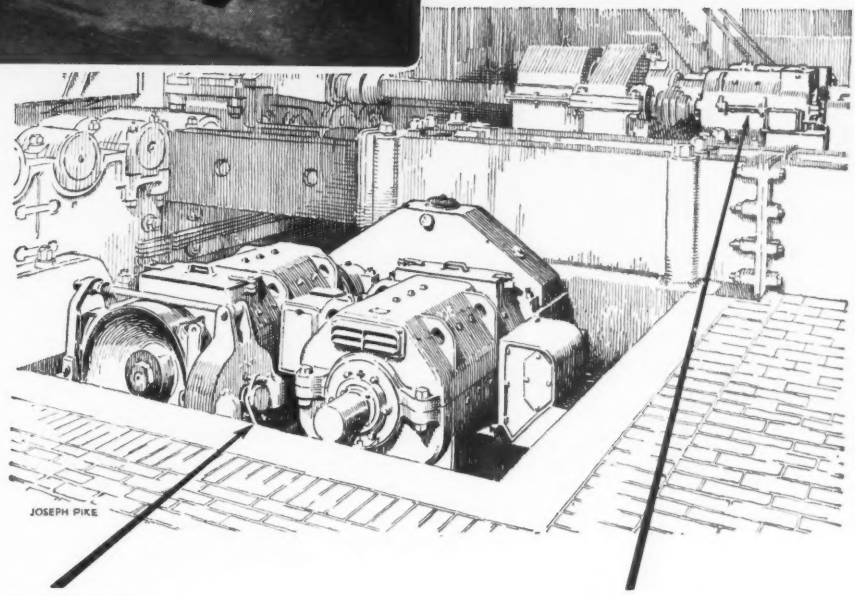

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Two 50 h.p. steelworks motors driving the manipulator fingers.

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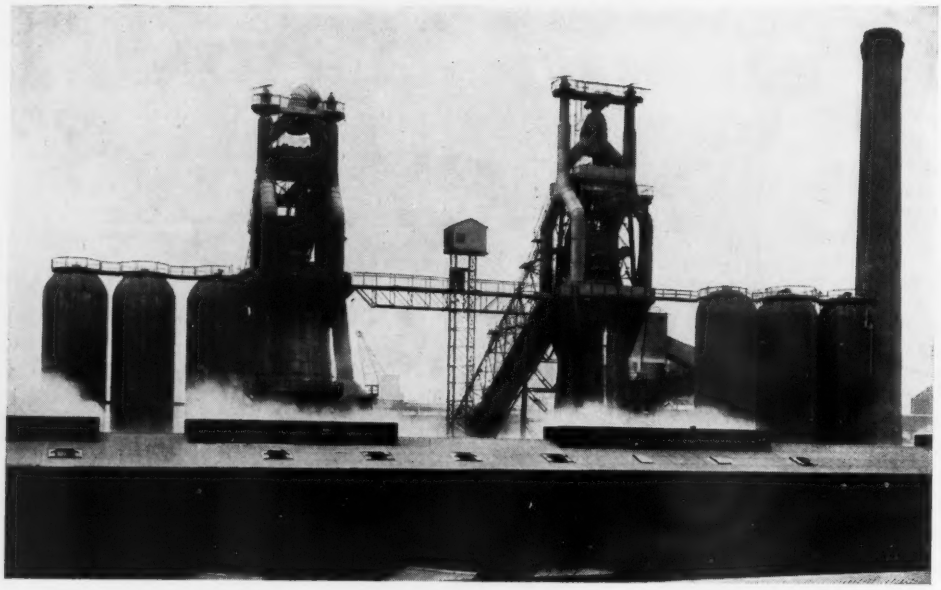

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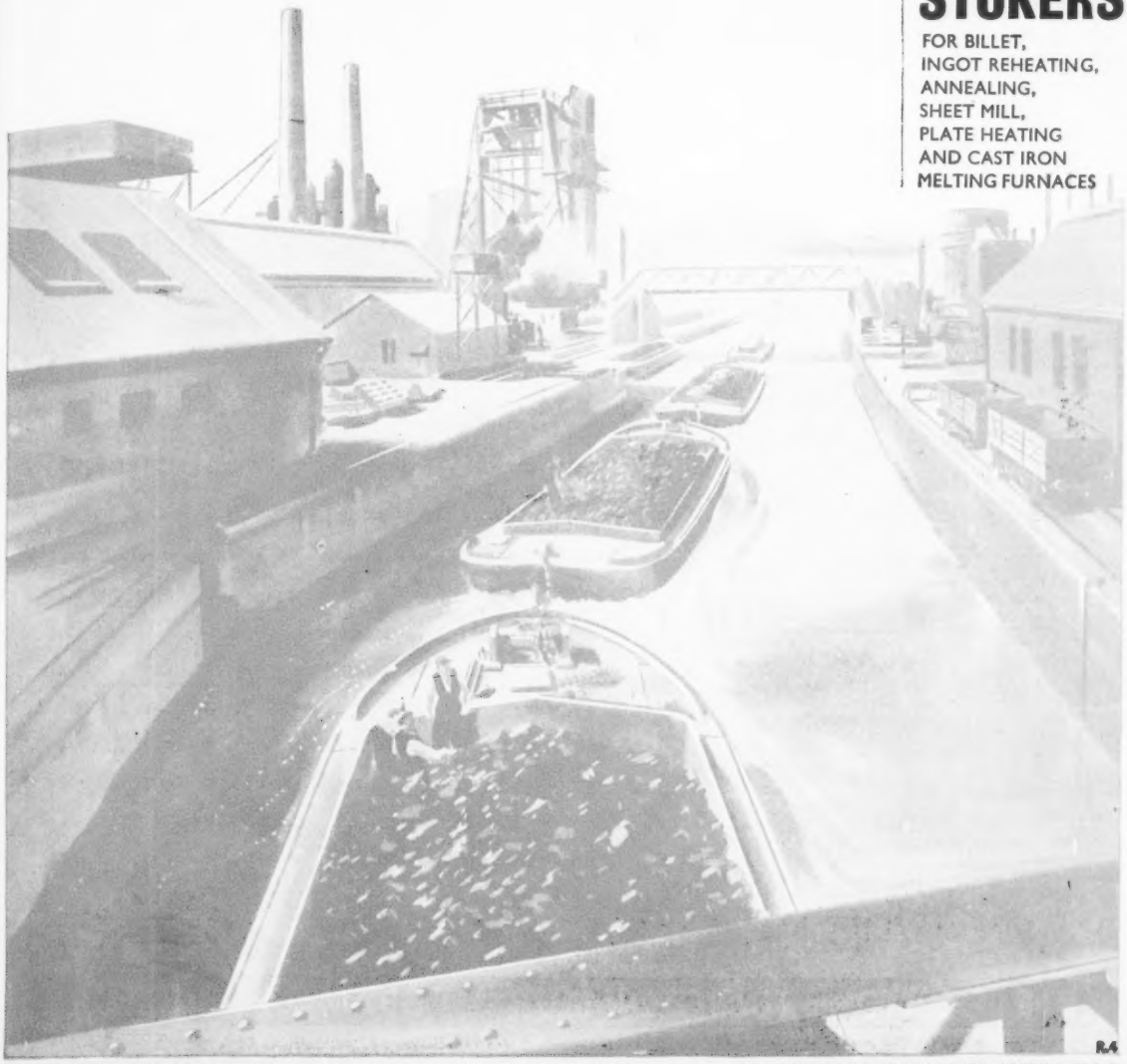

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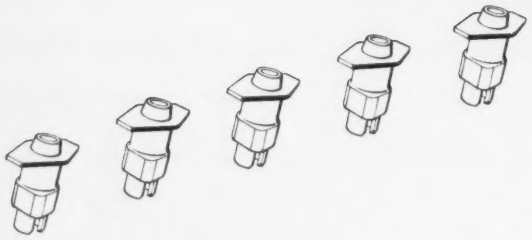
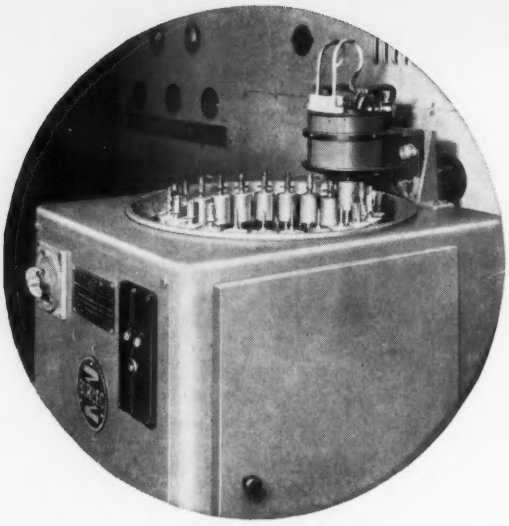
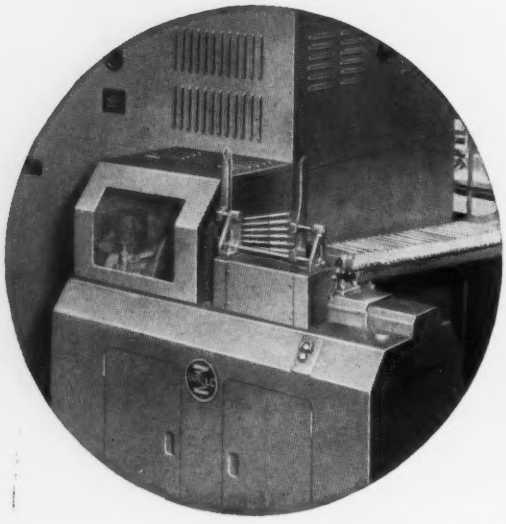
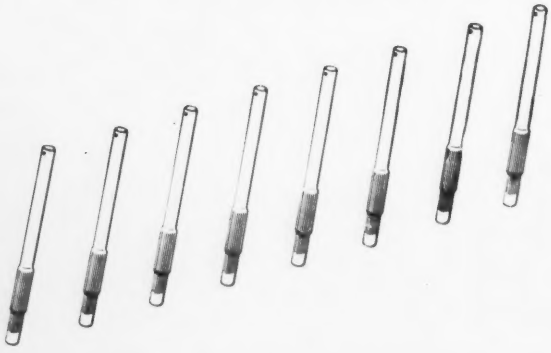




Repetition Heat Treatment





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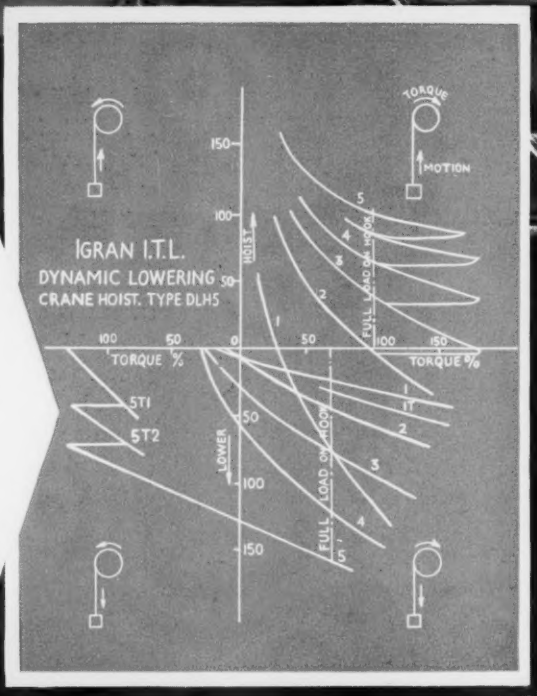

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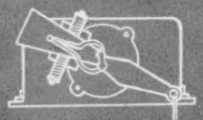

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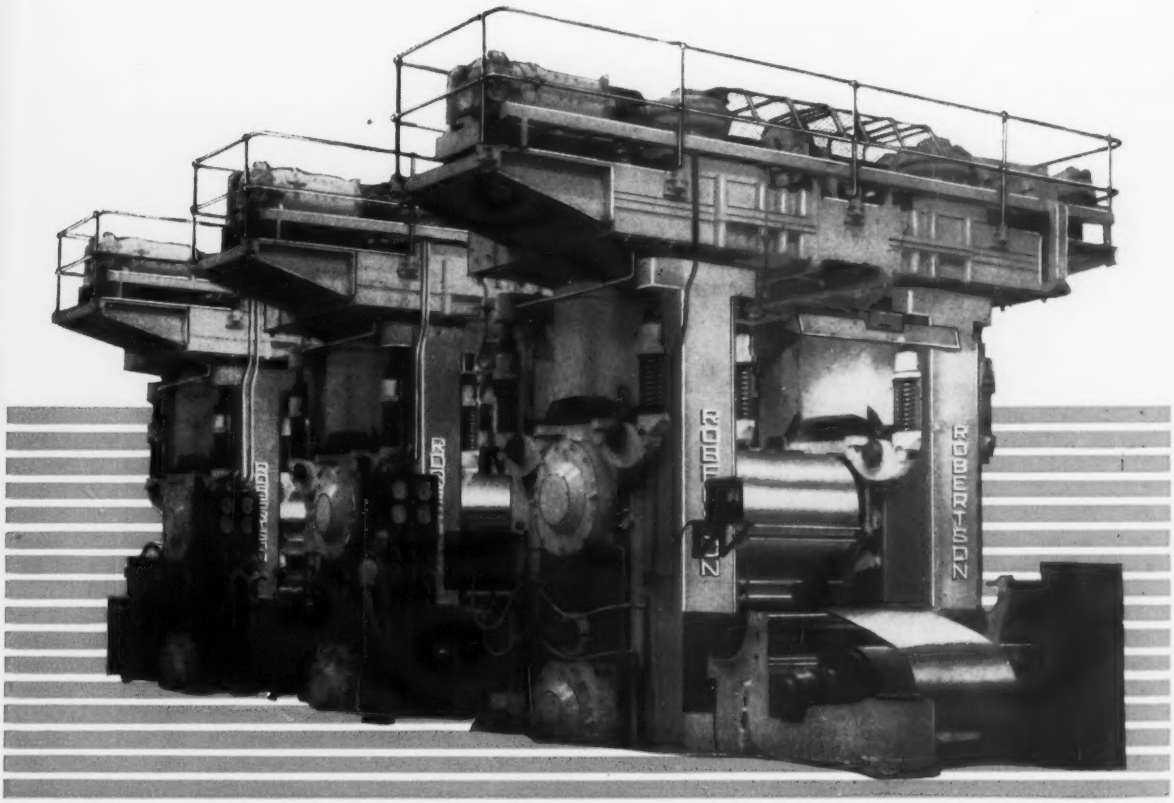

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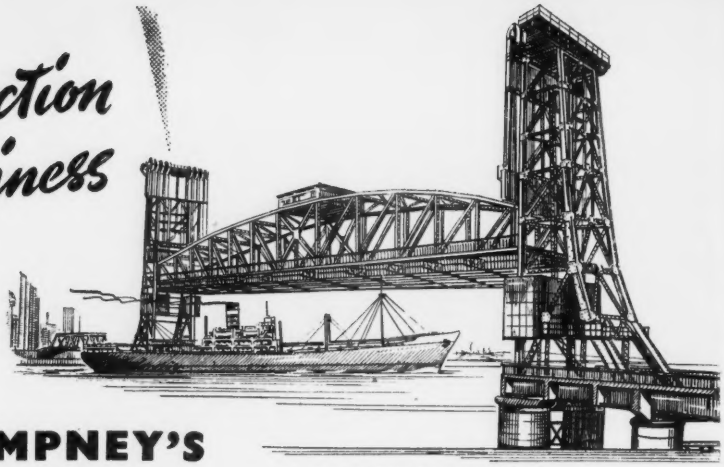

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and save material, reduce labour and maintenance costs

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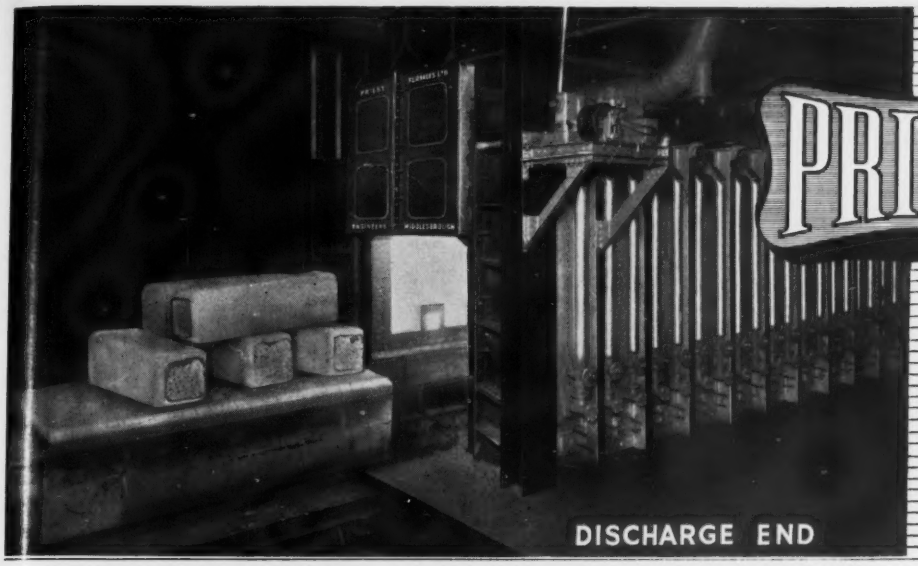
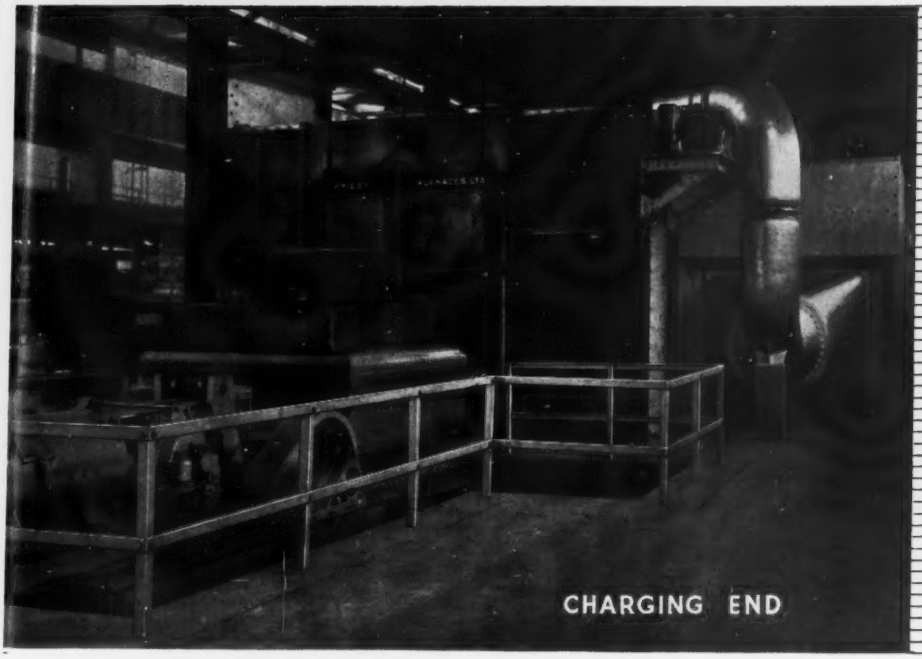


PRIEST FURNACES



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Duty—20 tons of ingots per hour heated from cold to 900 degs. C. for a fuel consumption of 8 therms per ton.

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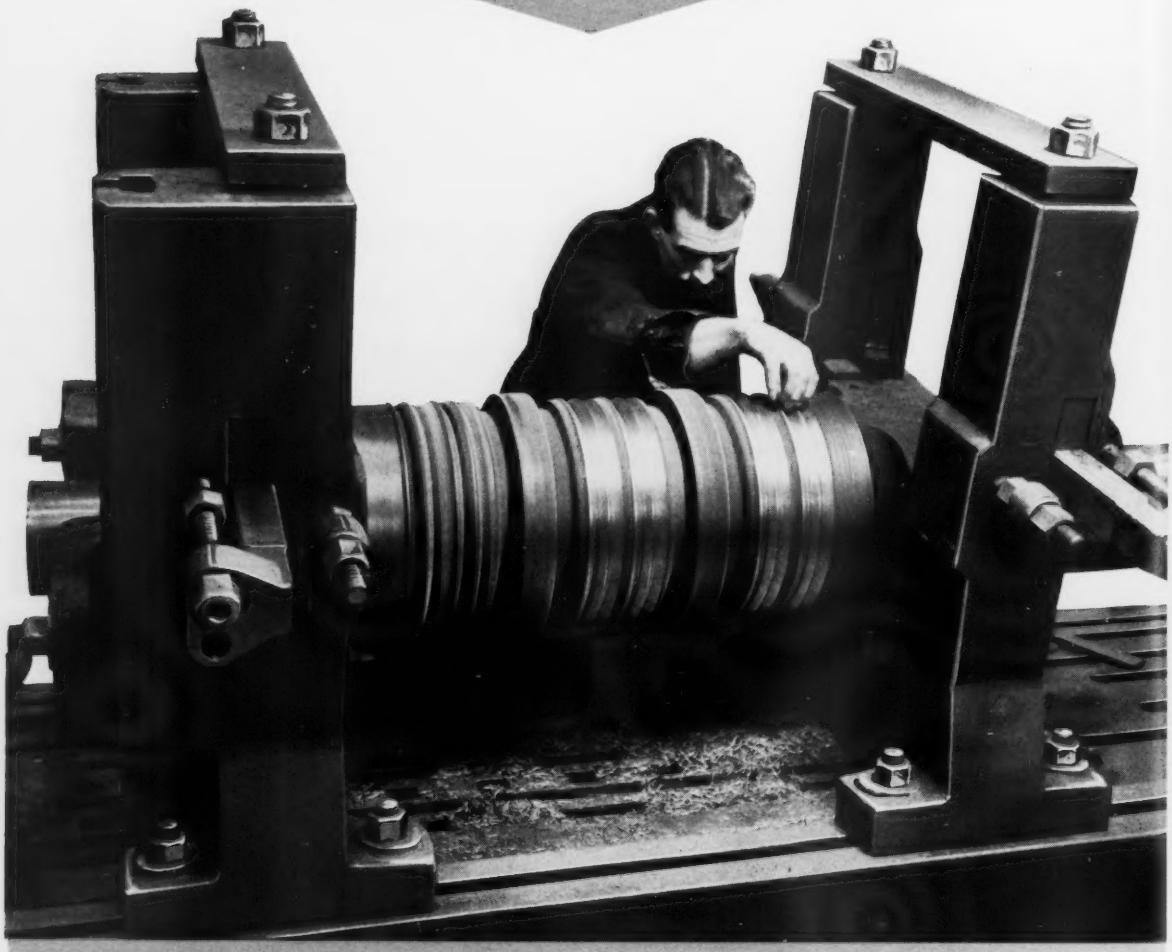

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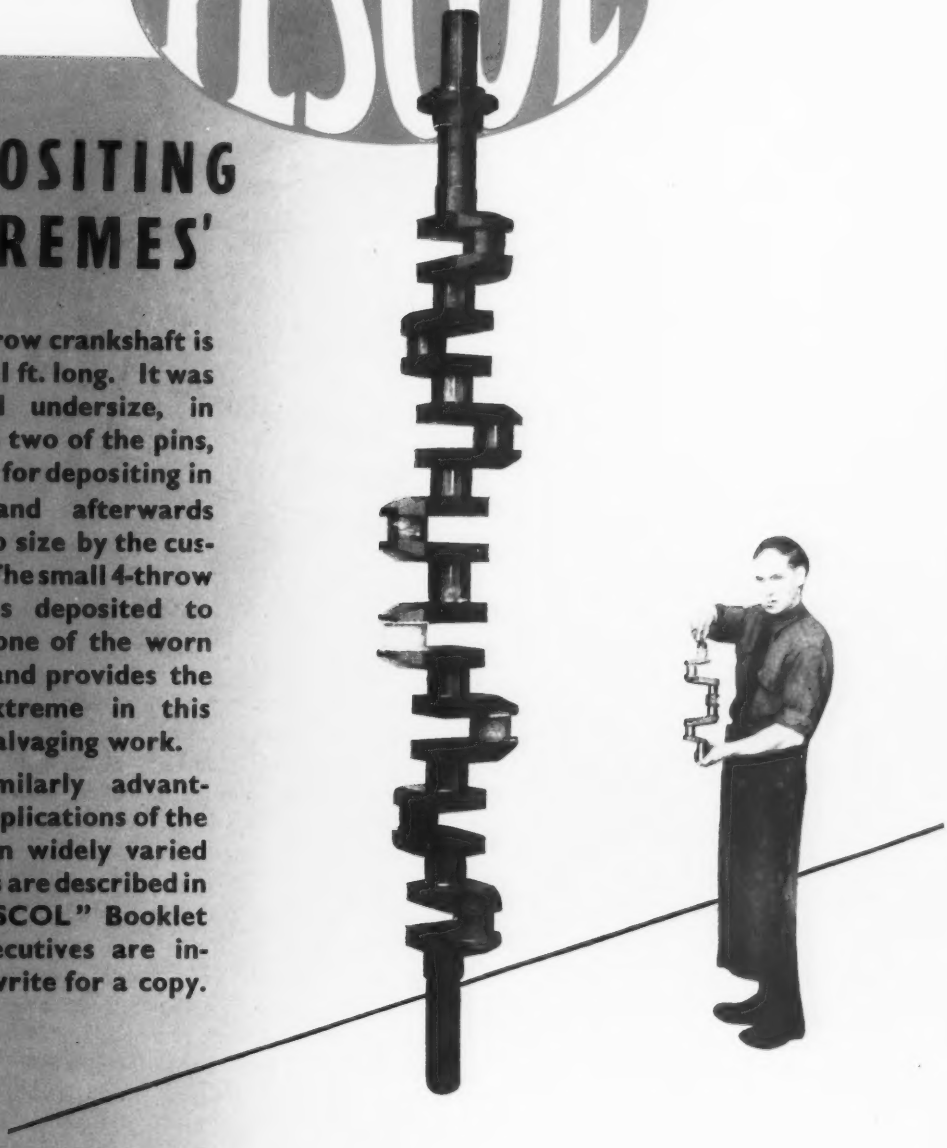

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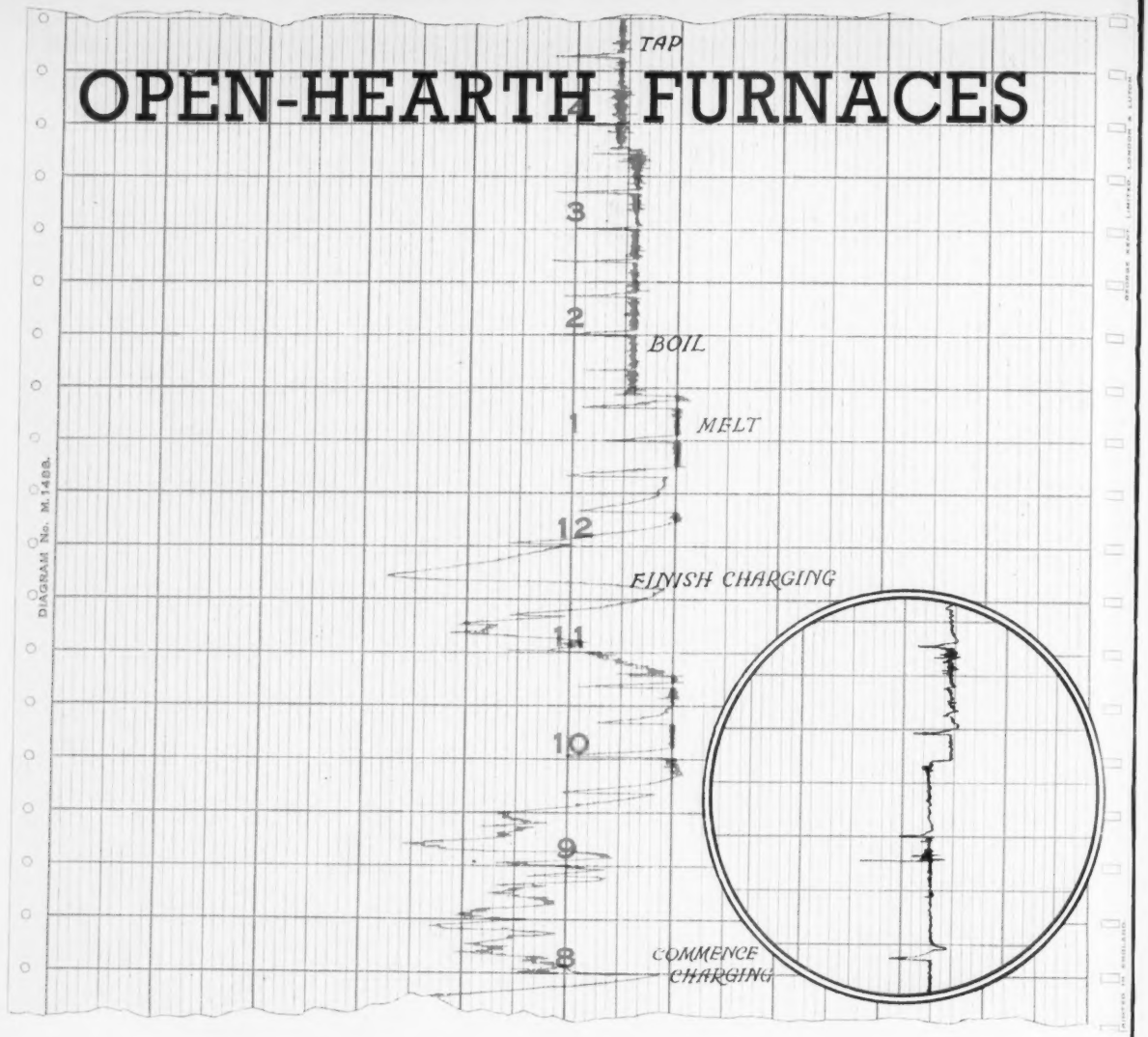

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Without precision temperature control, the attainment of the highest melting efficiency is prohibited by the need for restricting the furnace temperature to a figure well below the optimum, in order that peak fluctuations may not damage the roof lining.

George Kent Ltd., can now supply an automatic control system for maintaining the roof temperature between reversals within close limits. These portions of a chart show the results being obtained on a furnace fired by hot raw producer gas by Messrs. John Baker & Bessemer Ltd. The steep drops in temperature are due to furnace reversals. The chart is 10″ wide and one division of the chart corresponds approximately to 6°C. and the target temperature is maintained to the extremely close limits despite variations in the furnace conditions, thereby conducing to considerably increased output. In order to show the stability of control, the chart was experimentally run at three times the normal speed; a portion of this is shown in the circle.

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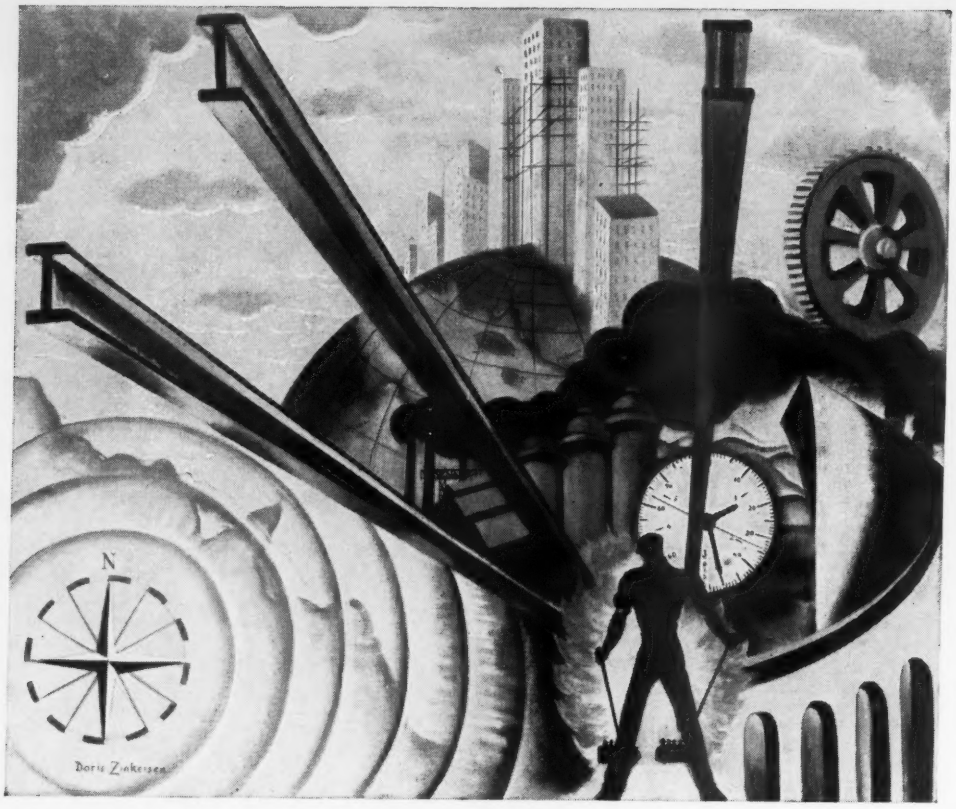

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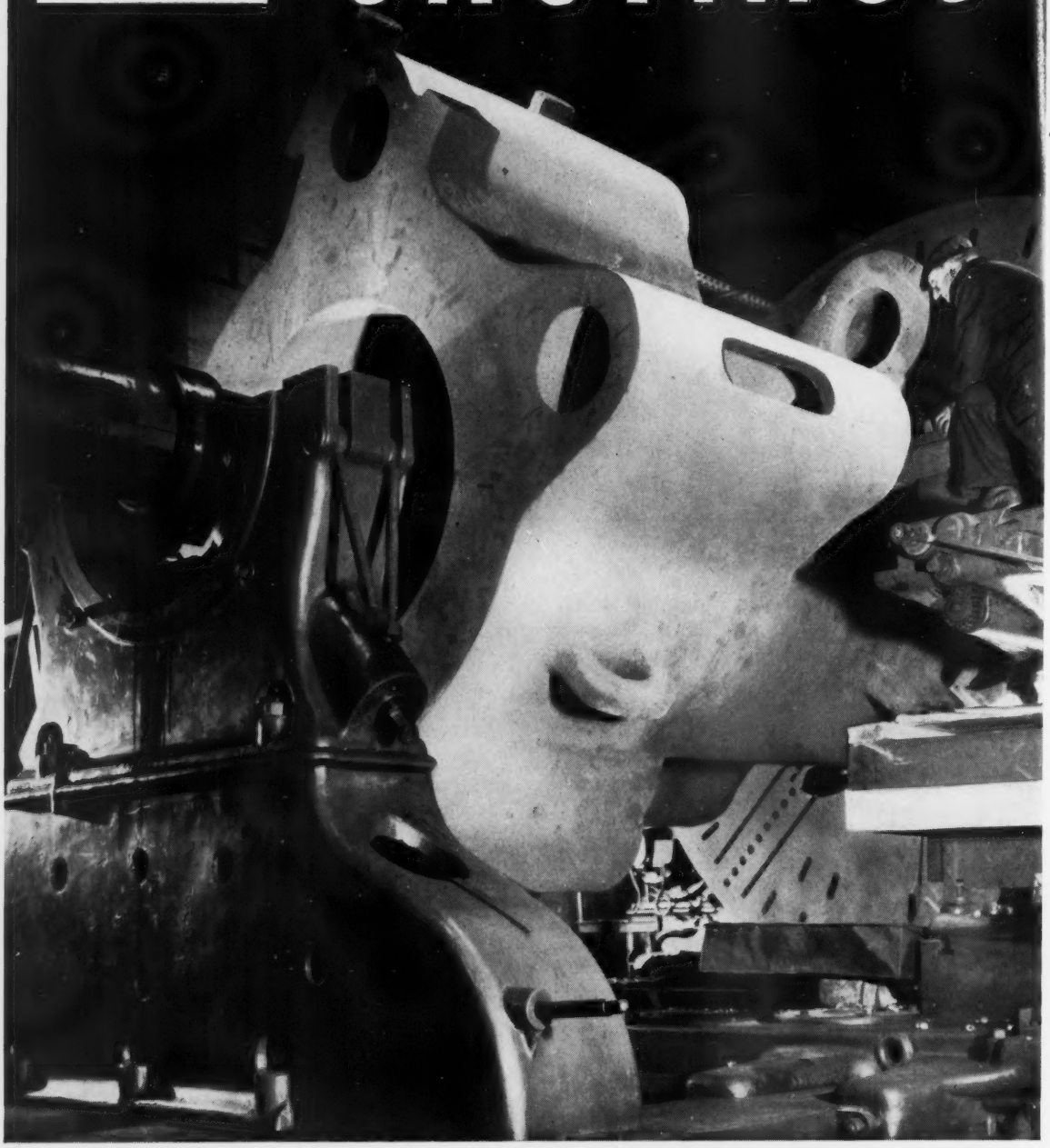

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SIR JOHN DUNCANSON

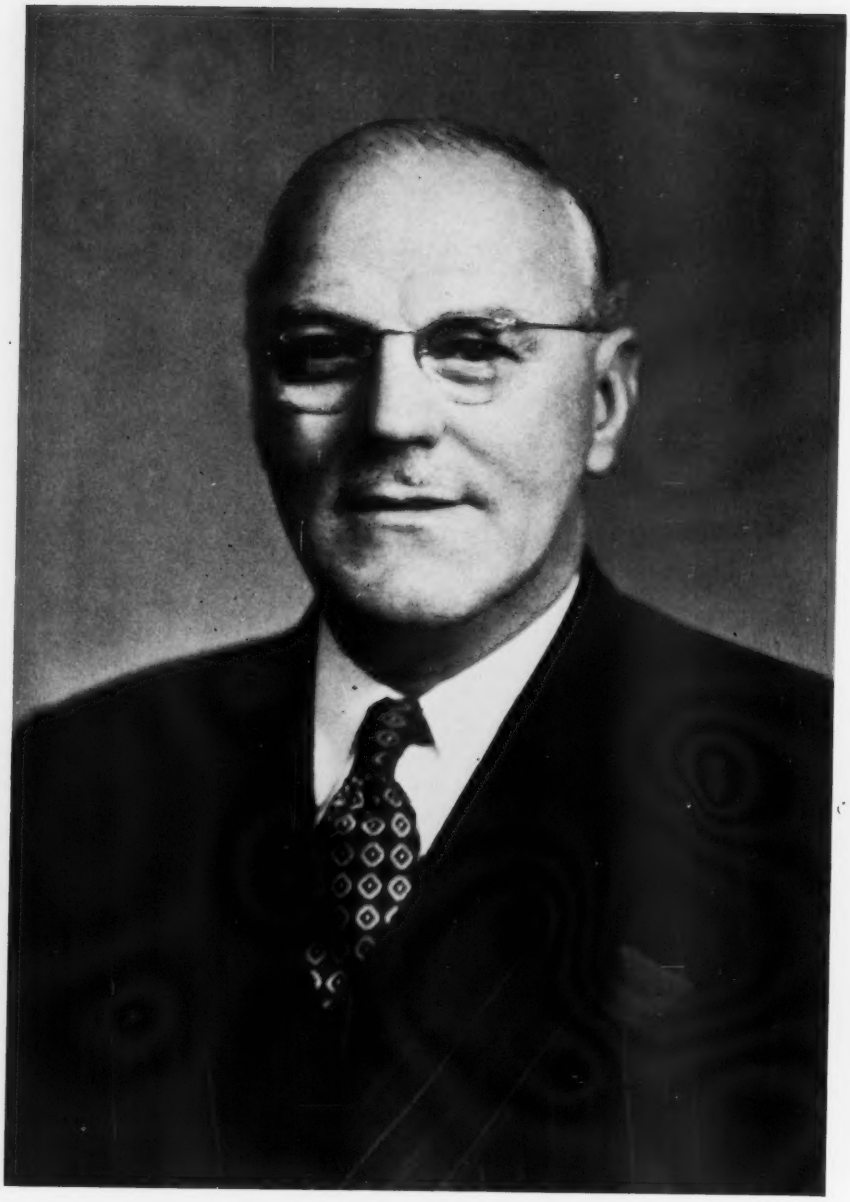
SIR JOHN McLEAN DUNCANSON was born in 1897. On leaving school in 1914, he immediately joined the Queen's Own Royal Glasgow Yeomanry with whom he served continuously until 1918.

At the end of the war, Sir John joined the Steel Company of Scotland, Limited, but withdrew from active participation in affairs in Scotland in 1939, when he was appointed Director of Heavy Steel Products and Deputy Controller of the Iron and Steel Control, Ministry of Supply, succeeding to the Controllership in 1942. Up to 1939 he had been an active Director of the Steel Company of Scotland, Deputy Chairman of R. Y. Pickering and Co., Limited, and a Director of various other engineering concerns. In 1943 he was appointed as the British member of the Anglo-American Steel Mission, which visited all the Dominions, India and the United States of America in connection with the manufacture and use of steel by the various allied countries. In recognition of his war-time services, Sir John was created Knight in 1942, and in 1947 he received the U.S. Medal of Freedom with Bronze Palm.

In 1945, Sir John resigned his position as Controller of Iron and Steel, Ministry of Supply, to assume the appointment of Technical and Commercial Director of the British Iron and Steel Federation. In this capacity he has been intimately concerned with plans for the extension and rehabilitation of British iron and steel works, and with the many improvements in manufacturing technique which have been, and are now, taking place. Early in 1949, Sir John will be leaving the British Iron and Steel Federation to become associated with certain interests of Sir John Lithgow.

His intimate knowledge of all sections of the industry has enabled him to fulfil with distinction his duties as a representative of the British Iron and Steel Federation on the Grand Council of the Federation of British Industries.

Sir John became a Member of The Iron and Steel Institute in 1936; he served as an Honorary Member of Council from 1945 to November, 1948, when he was nominated an Honorary Vice-President, in recognition of his distinguished services to the Institute and to the industry. He is the Chairman of the Iron and Steel Industry Standards Committee of the British Standards Institute. He is also a member of the Institute of Engineers and Shipbuilders in Scotland and of the West of Scotland Iron and Steel Institute.



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IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

The Structure of Carbides in Alloy Steels

By H. J. Goldschmidt, M.Sc., A.Inst.P.

Part I—GENERAL SURVEY

SYNOPSIS

The present paper is the first of a series giving an account of X-ray work on carbides liable to occur in alloy steels, especially high-speed steels. It is mainly concerned with the structures of carbides formed by iron, chromium, tungsten, and molybdenum, but these are considered as part of a broader systematic survey of carbide-forming tendencies of alloying elements and their relation to crystal structure.

A brief account is given of the relevant metal–carbon systems. The carbide structures are described and discussed, and an attempt is made to correlate them with their stability in the presence of given elements.

In the course of X-ray investigations on alloy steels carried out for Messrs. William Jessop and Sons, Ltd., over a number of years, the nature of the carbides liable to occur in a variety of steels has been elucidated, and attempts have been made to correlate their structure and phase assemblies in a systematic fashion. The object of the present account is to present some of the results of this survey. A number of specific problems arising will be discussed, centred around the systems iron–chromium–tungsten–carbon and iron–chromium–molybdenum–carbon, and data presented to permit the ready identification of carbides found in a given steel from their diffraction patterns. In spite of some outstanding researches on individual carbides, *e.g.*, that of Westgren's school, and the more recent work at the Cavendish Laboratory (*e.g.*, cementite structure), many gaps in our knowledge still remain, and if this investigation helps to point out and to fill some of these, it will have achieved its purpose.

It is not intended to deal with the structure of the primary steel phases (austenite, martensite, ferrite), except where they are closely bound up with the carbides.

In practice the quaternary system iron–chromium–tungsten–carbon, with molybdenum as alternative to tungsten, was given particular attention, since this covers a large number of steels and alloys of the most diverse properties, notably high-speed steels. It is found that by investigating seemingly quite unrelated alloys, in different regions of this system (*e.g.*, low chromium–molybdenum steels, high-speed steels, tungsten carbide hard-metal materials, ferro-chromes), considerable assistance is derived from one group of alloys in solving the characteristics of another. Further alloy elements, especially the strong carbide-forming ones like niobium, vanadium, and titanium, have to be given additional consideration, but even in this case the iron–chromium–tungsten (molybdenum)–carbon system forms a valuable starting point, if the broader view is taken that the compounds occurring in this system are not tied to the special chemical composition, but rather stand as representatives of certain structure types, which fall into one systematic scheme; the cubic carbide structure, *e.g.*, of NbC, although not represented in the present quaternary system, nevertheless forms an integral part of this scheme.

The present investigation will therefore fall into the following main sections:

(1) A brief review of data on metal–carbon binary and ternary systems formed by the chief steel-alloying elements: general discussion of carbide relationships (structures).

(2) The iron–chromium–tungsten (molybdenum)–carbon system: experimental results and discussion.

(3) Effect of certain additional elements.

THE METAL–CARBON BINARY SYSTEMS

The only steel-alloying elements to be dealt with are those covering the part of the periodic table

Manuscript received 29th April, 1948.

Mr. Goldschmidt is a Research Physicist at the B.S.A. Group Research Centre, Sheffield.

between the fourth and eighth group and the fourth and sixth row, *i.e.*:

Ti	V	Cr	Mn	Fe	Co	Ni	(Cu)
Zr	Nb	Mo	[Ma	Ru	Rh	Pd	Ag]
(Hf)	Ta	W	[Re	Os	Ir	Pt	Au]

The rare and noble metals shown in the square brackets may be discarded except for noting that silver, palladium, rhodium, ruthenium, gold, platinum, iridium, and osmium all form purely graphitic systems with carbon; but there is evidence to show that rhenium, if obtainable in commercial quantities, would promise to be of very considerable interest as an alloying element (Eggers[1]).

The binary diagrams are shown in summary form in Fig. 1 as far as data are available. In the following pages brief notes are given on each system, proceeding

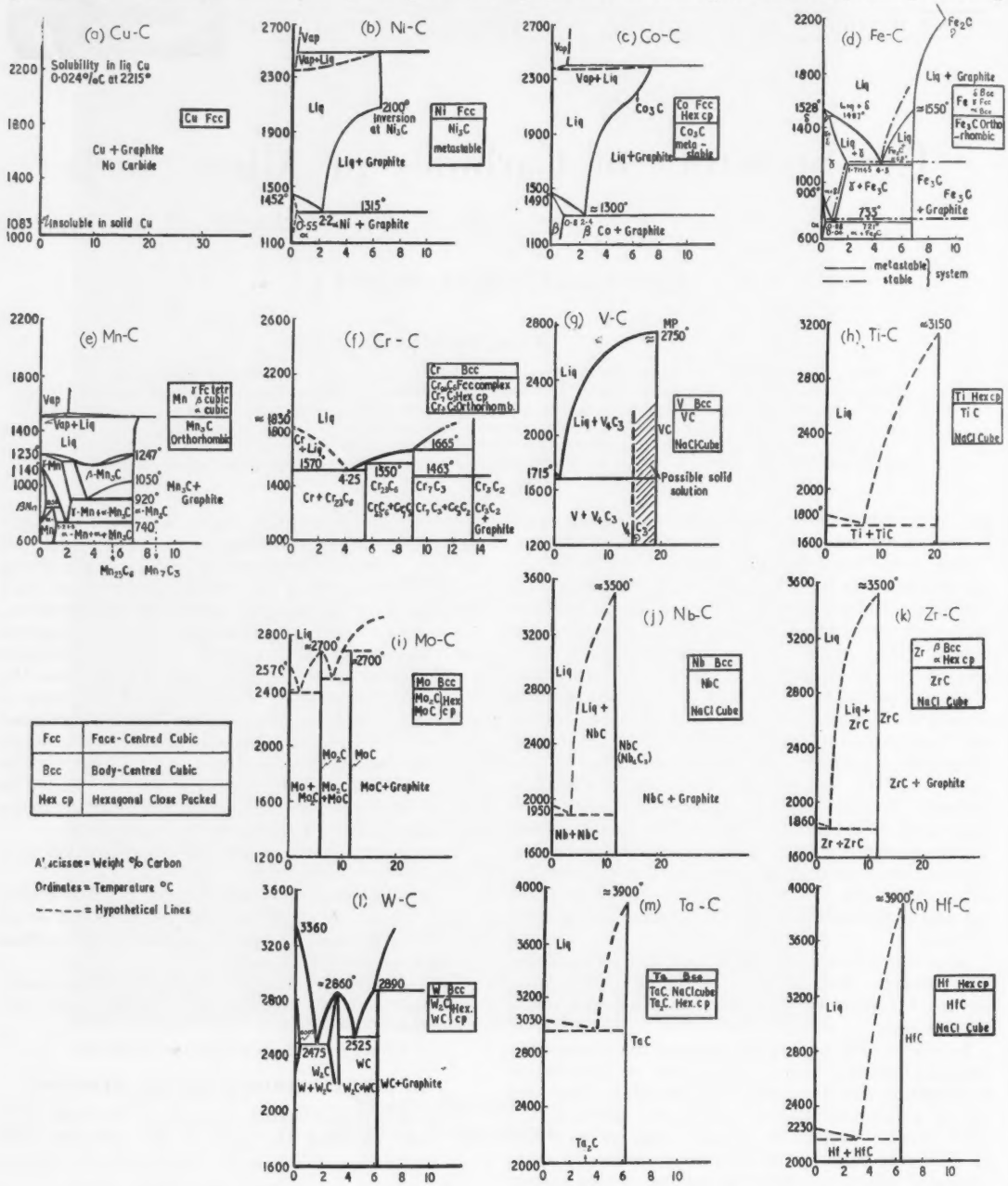


Fig. 1—Binary metal–carbon systems arranged according to the periodic table, with notes on structures of carbides and the parent metals

in order from the weakest to the strongest carbide-formers. Table I summarizes the chief data on simple carbides, *i.e.*, their compositions, melting points, densities, hardnesses, crystal structures, lattice dimensions, and heats of formation.

Copper–Carbon (Fig. 1 (*a*))

Copper forms no stable carbide, being in direct equilibrium with graphite at all temperatures. The existence of a metastable carbide has been suggested by Briner and Senglet,[2] which can be preserved by rapid quenching of the melt from 1600° C. Berthelot has synthesized two very unstable carbides Cu_2C_2 and CuC_2, which decompose spontaneously. In liquid copper, traces of carbon are dissolved (approximately 0·02% C at 1700° C.) ; there is no solubility of carbon in solid copper.

Nickel–Carbon (Fig. 1 (*b*))

The stable system is between nickel and graphite, there being virtually no solubility in solid nickel. However, as indicated in Fig. 1 (*b*), liquid nickel dissolves up to 6·4 wt.-% of carbon (atomic composition Ni_3C), a value approached between the eutectic point and 2100° C., above which it is maintained over a wide range of temperatures (Ruff and Martin[3]). This would indicate the formation of Ni_3C molecules already in the liquid. The metastable nickel carbide Ni_3C has been found by Briner and Senglet[2]; according to them, it is relatively stable above 1600° C. and below 300° C. It is necessary to cool rapidly out of the liquid from 2000° to 1000° C. in order to obtain the carbide. Bahr[4] and Schmidt[5] obtained Ni_3C by carburizing nickel at 250° C., but the compound already decomposes between 380° and 420° C. Morrogh and Williams,[6] in their recent work on graphite formation in cast irons, studied the nickel–carbon and cobalt–carbon systems and also concluded the existence of metastable nickel (and cobalt) carbide, which permits the formation of nodular graphite by undercooling. Additions such as calcium silicide can stabilize the carbide.

X-ray analysis of Ni_3C by Jacobson and Westgren[7] gave a hexagonal close-packed structure. This structure is, however, in conflict with that reported later by Kohlhaas and Meyer,[8] according to whom Ni_3C possesses the orthorhombic cementite structure (Fe_3C). The cementite structure is considered as much more probably the correct one, on the grounds of periodic classification. The hexagonal structure of Westgren and Jacobson may have corresponded to a second form of primary nickel, analogous to hexagonal cobalt, which is only rendered stable by some carbon in solid solution. In fact, sputtered or electrolytic nickel is apt to take the hexagonal structure (Bredig and Bergkampf[9]), with lattice dimensions $a = 2·66$ kX, $c/a = 1·61$, which is almost the same as the values given by Westgren and Jacobson for Ni_3C : $a = 2·646$ kX, $c/a = 1·636$.

Cobalt–Carbon (Fig. 1 (*c*))

The stable system, a eutectic one, is between cobalt and graphite. Solid cobalt dissolves 0·82% of carbon at 1300° C., 0·33% at 1000° C., and 0·1% after slow cooling, according to Boecker,[10] while Hashimoto[11] observes a solubility of up to 1·1% of carbon at the eutectic temperature (approximately 1315° C.). A point on which there appears to be no information and which is worth investigating is whether higher solubility exists in the cubic than in the hexagonal form of the metal. A metastable carbide, of probable formula Co_3C, has been reported by Schenck and Klas,[12] while Ruff and Keilig[13] also concluded the existence of Co_3C molecules in the liquid. Liquid cobalt dissolves variable amounts of carbon, the maximum value being reported at 7·4 wt.-% of carbon (28 at.-%) ; the accuracy of this must be questioned, but again the value is significantly near Co_3C. However, the carbide appears to be highly unstable. Morrogh and Williams[6] also affirm the existence of cobalt carbide and found it slightly more stable than Ni_3C. Meyer[14] prepared Co_3C and determined its structure, finding it to be isomorphous with cementite. The lattice dimensions of Ni_3C, Co_3C, and Fe_3C, are given in Table I.

A carbide Co_2C has been reported by Bahr and Jessen,[15] and its existence has been confirmed in a recent paper by Hofer and Peebles.[16] It has been prepared by carburization of cobalt powder at 218° C. and is unstable. The latter authors give its diffraction pattern, which differs from that of Fe_2C (Jack,[18] *see* below), but the structure is not solved.

Iron–Carbon (Fig. 1 (*d*))

The iron–carbon system, iron–graphite (strictly the equilibrium one), and the " metastable " system involving cementite, do not require description here. Cementite Fe_3C is always the prevalent carbide in plain carbon and low-alloy steels. The existence of iron percarbide Fe_2C, having been suggested by Hägg,[17] has recently been re-affirmed by Jack,[18] who found it to possess a small range of composition, *i.e.*, from 30·5 to 32·1 at.-% of carbon, and who also determined its structure. This is probably orthorhombic, with four $Fe_{20}C_9$ molecules. The cell dimensions are :

$$a = 9·04 \text{ kX}, b = 15·66 \text{ kX}, c = 7·92 \text{ kX}.$$

Jack obtained Fe_2C by the action of carbon monoxide on iron nitrides below 500° C., above which Fe_3C is formed. Fe_2C is also metastable.

It is of interest in this connexion to note the liquid solubility of carbon in iron (*see* Fig. 1 (*d*)). Above the melting point of cementite (approximately 1550° C.) the liquid solubility for carbon gradually increases from 25 to a maximum of 33 at.-% of carbon at 2200° C., indicating the formation in the liquid of molecular aggregates, first of Fe_3C and then of Fe_2C.

The structure of Fe_3C has originally been determined by Westgren and Phragmen[19] and Hendricks,[20] and has been re-determined by Lipson and Petch.[21] Its unit cell is shown in Fig. 6 ; it is orthorhombic and contains four molecules (16 atoms). The cell dimensions are[21] :

$$a = 4·5144 \text{ kX}, b = 5·0787 \text{ kX}, c = 6·7297 \text{ kX}$$

Hume-Rothery, Raynor, and Little[22] slightly modified these values, while Petch[23] further discussed the structure and affirmed that its composition does not deviate from Fe_3C. A further discussion on cementite will follow later.

The unit cells of Fe_3C and Fe_2C, both orthorhombic, show a simple relationship, as follows :

$$\left.\begin{array}{l} {}^{a}Fe_2C \simeq 2\times {}^{a}Fe_3C \\ {}^{b}Fe_2C \simeq 3\times {}^{b}Fe_3C \\ {}^{c}Fe_2C \simeq 1\times {}^{c}Fe_3C \end{array}\right\} \text{(though slightly elongated)};$$

so that six Fe_3C cells stacked together form a region similar to, but slightly smaller than, one of Fe_2C. This volume contains eight more iron atoms in Fe_2C and twelve more carbon atoms. This excess in the number of atoms is almost exactly accounted for by the difference in equivalent volumes, *viz.* :

In Fe_3C : 96 atoms (72 iron, 24 carbon) ; volume occupied 924 kX^3.
In Fe_2C : 96 atoms (64 iron, 32 carbon) ; volume occupied 934 kX^3.

The increased carbon content in Fe_2C therefore involves no major expansion or contraction from Fe_3C, and the transition can probably take place in the presence of excess carbon without major change in structure.

Manganese–Carbon (Fig. 1 (*e*))

Figure 1 (*e*) shows the manganese–carbon binary system, according to Vogel and Döring.[24] Manganese forms at least one stable carbide Mn_3C, which is claimed to exist in two forms, α- and β-Mn_3C. The high-temperature β form possesses a high solubility for manganese ; α-Mn_3C is isomorphous with cementite and completely intersoluble with it (Jacobson and Westgren[7]). The latter authors also quote Öhman's findings of two further carbides, *i.e.*, $Mn_{23}C_6$ and Mn_7C_3, analogous to and of the same crystal structure as $Cr_{23}C_6$ and Cr_7C_3. This was confirmed in an important paper by Öhman.[25]

The three allotropic forms of manganese dissolve carbon up to the following limits, according to Vogel and Döring[24]:

γ-manganese : 2·0% carbon at 920° C.
β-manganese : 0·4% carbon at 850° C.
α-manganese : 1·3% carbon at 740° C.

It may be seen from Fig 1 (*e*) that the high-temperature form of Mn_3C (β) and γ-manganese possess a considerable mutual solubility. It is questioned, however, whether the presumed "β-Mn_3C solid solution" does not correspond to Westgren's carbide $Mn_{23}C_6$; a re-determination of this important system is desirable.

Liquid manganese dissolves carbon up to the composition Mn_3C, similar to the observations on iron–carbon, cobalt–carbon, and nickel–carbon. Again the formation in the liquid of molecular aggregates of Mn_3C seems probable.

Chromium–Carbon (Fig. 1 (*f*))

The existence of the three carbides $Cr_{23}C_6$, Cr_7C_3, and Cr_3C_2, is firmly established through Westgren and Phragmen's work.[26] Earlier work includes that by Moisson,[27] Ruff and Föhr,[28] and Arnold and Read.[29] A carbide Cr_5C_2 reported by Ruff and Föhr probably corresponds to Cr_7C_3. $Cr_{23}C_6$ forms a eutectic system

Table I

DATA ON BINARY CARBIDES

Carbide of:	Formula	Melting Point (approx.), °C.	Density	Hardness	Crystal Structure	Lattice Dimensions, kX	Heat of Formation[23] K cal./mol. at 20–25° C. 1 atm.-ΔH
Nickel	Ni_3C*	..	..	..	Orthorhombic, cementite-type[3] (Hex. c.p.)[7]	$\left\{\begin{array}{l} a = 2{\cdot}646 \\ c/a = 1{\cdot}636 \end{array}\right\}$	+ 9 approx.
Cobalt	Co_3C*	..	..	..	Orthorhombic, cementite-type	$a = 4{\cdot}52$ $b = 5{\cdot}08$ $c = 6{\cdot}73$	..
Iron	Fe_3C	1650	7·67	840 Brinell[22]	Orthorhombic	$a = 4{\cdot}5144$ $b = 5{\cdot}0787$ $c = 6{\cdot}7297$	+ 2·5 approx. ‡
	Fe_2C	..	..	..	Orthorhombic[14]	$a = 9{\cdot}04$ $b = 15{\cdot}66$ $c = 7{\cdot}92$	..
Manganese	Mn_3C	1520	..	..	Orthorhombic, cementite-type	..	− 23 ± 2
	$Mn_{23}C_6$	..	..	..	Cubic (complex),[7] as $Cr_{23}C_6$	$a = 10{\cdot}564$	..
	Mn_7C_3	..	..	..	Hexagonal (as Cr_7C_3)[7]	$a = 13{\cdot}87$ $c = 4{\cdot}53$	..
Chromium	$Cr_{23}C_6$	1550	6·97	..	Cubic (complex)	$a = 10{\cdot}638$	..
	Cr_7C_3	1665	6·92	..	Hexagonal	$a = 13{\cdot}98$ $c = 4{\cdot}523$	..
	Cr_3C_2	1890	6·68	..	Orthorhombic	$a = 2{\cdot}821$ $b = 5{\cdot}52$ $c = 11{\cdot}46$	..
Vanadium	V_4C_3 VC	2830	5·36	9–10 Moh's scale	Cubic c.p.	$a = 4{\cdot}30$[24] or $= 4{\cdot}152$[25]	..
Titanium	TiC	3140 ± 90	4·25	8–9	Cubic c.p.	$a = 4{\cdot}3189$[12] or $= 4{\cdot}3251$[13]	− 114 ± 2
Molybdenum	Mo_2C	2687 ± 50	8·9	7–9	Hexagonal c.p.	$a = 2{\cdot}99$ $c/a = 1{\cdot}58$	..
	MoC	2692 ± 50	8·58	7–8	Hexagonal c.p.	$a = 4{\cdot}88$ $c/a = 1{\cdot}34$	..
Niobium	NbC (Nb_4C_3)	3500 ± 125	7·82	..	Cubic c.p.	$a = 4{\cdot}4404$	..
Zirconium	ZrC	3550	6·90	8–9	Cubic c.p.	$a = 4{\cdot}687$	− 45 ± 2
Tungsten	α-W_2C†	2857 ± 50	17·20	9–10	Hexagonal c.p.	$a = 2{\cdot}99$ $c/a = 1{\cdot}575$	..
	WC	2867 ± 50	15·50	+ 9	Hexagonal c.p.	$a = 2{\cdot}894$ $c/a = 0{\cdot}973$	..
Tantalum	Ta_2C	..	..	..	Hexagonal c.p.	$a = 3{\cdot}091$ $c/a = 1{\cdot}595$	..
	TaC	3875 ± 150	14·48	+ 9	Cubic c.p.	$a = 4{\cdot}445$	..
Hafnium	HfC	3887 ± 150	12·20	..	Cubic c.p. (probably)	..	..

* Unstable, but retainable; persistent in melt † Transformation α-$W_2C \rightarrow$ β-W_2C above 2400° C. ‡ Variously reported between − 20 and + 8

with chromium, but the formation of this carbide is sluggish and can be suppressed by rapid cooling. In that case the metastable system Cr–Cr_7C_3 prevails. Figure 1 (*f*) shows the diagram according to Friemann and Sauerwald,[30] including the metastable system.

The crystal structures have been determined mainly by Westgren's school, and are as follows:

$Cr_{23}C_6$[31] (referred to earlier as Cr_4C, but the modified formula should be accepted) = complex face-centred cube with 116 atoms per unit cell (92 chromium, 24 carbon).
Edge of unit cube = 10·638 kX.
Cr_7C_3 = hexagonal[32] with 80 atoms (56 chromium, 24 carbon) per unit cell; a = 13·98 kX, c/a = 0·324 kX.
Cr_3C_2 = orthorhombic[33] with 20 atoms (12 chromium, 8 carbon) per unit cell; a = 2·821 kX, b = 5·52 kX, c = 11·46 kX.

The solid solubility of carbon in chromium is practically nil. (The chromium carbides will be considered in more detail below.)

Vanadium–Carbon (Fig. 1 (*g*))

The stable vanadium carbide has the cubic NaCl type of structure. Its composition has been reported as either VC or V_4C_3, but both may exist independently. The lattice parameter has been reported as a_0 = 4·30 kX,[34] while Maurer, Döring, and Pulewka[35] determined the identical spacing $a_0 = 4·152 \pm 0·05$ kX for what they presume to be two different compounds VC and V_4C_3. It is probable that a solid solution VC–V_4C_3 exists (defect lattice, carbon atoms being omitted from the ideal NaCl cell), and that the values 4·30 and 4·13 kX (Osawa and Oya[36]) apply to approximately the two ends of the range. In steels the carbide V_4C_3 is liable to appear. Desch,[37] in an account on iron–carbon–vanadium alloys, reaffirms this composition, which Wever, Rose, and Eggers[38] include in their ternary diagram as the only one.* A carbide V_2C has been noted by Osawa and Oya of hexagonal close-packed structure which, however, remains very doubtful, and may have been produced by impurities (nitrogen) present (Hansen[40]).

Figure 1 (*g*) gives the vanadium–carbon diagram based on the work of Ruff and Martin[41]; V_4C_3 has also been tentatively inserted.

Titanium–Carbon (Fig. 1 (*h*))

The very stable titanium carbide TiC is of the NaCl type of structure[34] (a_0 = 4·3189 kX, according to Metcalfe's[42] recent paper on the WC–TiC system). A compound Ti_2C, analogous to V_2C, has also been suspected to exist of a hexagonal close-packed structure (Jacobson and Westgren[7]), but this is uncertain. Hume-Rothery's[43] work on TiC and on its solubility with TiN (and that of other workers) showed that in titanium-bearing steels carbon is tied to form TiC up to the limit of available titanium. In the presence of stronger carbide-formers (*e.g.*, tungsten, niobium, tantalum) TiC tends to be at least partially intersoluble with the additional carbide; in conjunction with WC, TiC plays an important part in hard-metal metallurgy, which will be referred to later.

Figure 1 (*h*) indicates the titanium–carbon system, though this, as are some of the subsequent systems, is mainly tentative.

Molybdenum–Carbon (Fig. 1 (*i*))

The stable molybdenum carbides Mo_2C and MoC are known. In both, the metal atoms are arranged in a hexagonal close-packed lattice with interstitial hexagonal sheets of carbon atoms (Westgren and Phragmen[44]). These authors, however, consider Mo_2C to be a solid solution of carbon in metallic molybdenum, while Hoyt[45] and most other observers adhere to the existence of the independent compound. Complete intersolubility between the body-centred cubic molybdenum and hexagonal Mo_2C is, of course, not possible. Sykes, van Horn, and Tucker[46] found that Mo_2C forms a eutectic with molybdenum at 1·8% of carbon and 2200° C. Mo_2C is formed by peritectic reaction between 5·5 and 10% at 2400° C. The solubility of carbon in solid molybdenum is very small, becoming 0·09% at 1500–2000° C.

The molybdenum–carbon diagram is represented in Fig. 1 (*i*).

Niobium–Carbon (Fig. 1 (*j*))

The niobium carbide NbC is stable and of the NaCl type of structure[34] (Friederich and Sittig[47]; the spacing observed by the author is a_0 = 4·4404 kX). McKenna[48] observed a_0 = 4·4578 kX for NbC. No further carbide is formed by niobium. However, Eggers and Peter,[49] in investigating the iron–niobium–carbon system, found the formula Nb_4C_3 more nearly correct than NbC (Agte and Altherthum[50]). Their observed lattice parameter is a_0 = 4·46 kX, *i.e.*, larger than that given by Friederich and Sittig[47] and the present value. The formula Nb_4C_3 has not been verified, and some indirect but questionable support may be derived from V_4C_3, vanadium being of the same valency as niobium. A homogeneity range NbC/Nb_4C_3, similar to the suggested VC/V_4C_3, possibly exists.

Zirconium–Carbon (Fig. 1 (*k*))

The stable ZrC[34] has the NaCl type of structure (a_0 = 4·687 kX[51]). A second zirconium carbide ZrC_2 has been suspected by Ruff and Wallstein,[52] but this was probably a mixture of ZrC + C.[40]

Tungsten–Carbon (Fig. 1 (*l*))

The carbide WC, which forms the basis of sintered hard-metals, has been investigated by numerous workers; its structure is hexagonal close-packed, isomorphous with MoC (Westgren and Phragmen[44]).

* The following observation may be mentioned here in evidence. An annealed high-speed steel sample rich in vanadium showed, on X-ray examination, besides ferrite and the normal carbide Fe_4W_2C, a cubic carbide of NaCl type of structure, which would agree with vanadium carbide, lattice parameter a_0 = 4·17 kX. This would indicate a composition deficient in carbon (vacant metalloid sites in VC). A solid solubility of vanadium in VC has been presumed by Hägg[39] to extend from VC to V_2C, and for a composition 14·1 wt.-% of carbon the spacing 4·13 kX has been reported by Osawa and Oya.[36] Assuming this value to be correct and Vegard's law to apply up to VC (19·1 wt.-% of carbon), the present composition follows to be 15·3 wt.-% of carbon = 43 at.-%, *i.e.*, of a formula very near Desch's V_4C_3 (= 42·86 at.-% of carbon).

The second carbide W_2C,* isomorphous with Mo_2C, also has hexagonal symmetry, but Westgren considers this as a solid solution of carbon in metallic tungsten, the metal being supposed to possess a hexagonal form. The existence of W_2C as an independent compound has, however, been confirmed by Sykes[53] (among others). There is also a conflict as to whether WC and W_2C are largely or even completely intersoluble, or are two separate compounds. Certain research has supported the solid-solution-range theory, *i.e.*, W_2C would be in effect WC with a deficiency of carbon atoms. WC and W_2C show structural relationships (to be discussed in a later section) which make such an intersolubility of particular interest. W. P. Sykes,[53] Adelskjold, Sundelin, and Westgren,[54] and Becker[55] established the existence of the two independent

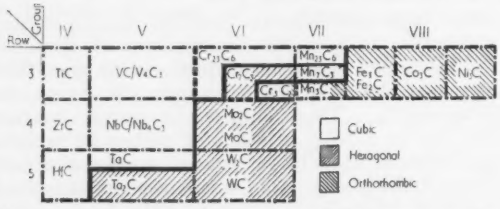


Fig. 2—Relationship between carbide structure and the position of the metal in the periodic table

carbides. K. Becker[55–57] found W_2C to exist in two modifications (α- and β-W_2C). The α–β transformation occurs at 2400° C., but by rapid cooling β-W_2C can be partially preserved ; it transforms into the α form by mechanical work. The structure of β-W_2C is not known, but, according to Becker, the pattern produced by the phase almost agrees with that of α-W_2C, though indicating a higher symmetry, the transformation being similar to the relation of α and β quartz.

Sykes' tungsten–carbon diagram is shown in Fig. 1 (*h*). It gives the main phase-equilibria with fair certainty, but the α–β forms of W_2C are omitted.

A recent paper by Horsting[58] confirms that W_2C is capable at high temperatures of dissolving limited amounts of tungsten as well as carbon. Reference should also be made to two recent papers on the powder metallurgy of tungsten carbide by Brownlee, Geach, and Raine,[59] and by Sandford and Trent.[60] The solid solubility of carbon in tungsten is negligible.

Tantalum–Carbon (Fig. 1 (*m*))

The very stable tantalum carbide TaC has the NaCl type of structure[34] ($a = 4{\cdot}445$ kX).[51] According to Burgers and Basart[51] the carbide Ta_2C also exists and possesses the hexagonal close-packed structure and probably two allotropic forms similar to W_2C. McKenna[48] re-determined the lattice dimensions of TaC, agreeing with Burgers and Basart.

Hafnium–Carbon (Fig. 1 (*n*))

Hafnium carbide HfC,[34] which possesses the highest melting point among all simple carbides, probably has the NaCl type of structure ; the only evidence for this is that Agte and Alterthum[50] reported a continuous series of solid solutions TaC–HfC.

* *Cf.* Table I for lattice dimensions.

STRUCTURE RELATIONS AMONG CARBIDES

Classified by their structure symmetry, the binary carbides reviewed above possess one of three types of structures :

Class 1, cubic (NaCl type) : TiC, V_4C_3, ZrC, NbC, TaC
Class 2, hexagonal close-packed : Mo_2C, MoC, W_2C, WC, Ta_2C
Class 3, orthorhombic : Fe_3C, Fe_2C, Mn_3C, and (probably) Co_3C and Ni_3C

There is a simple relationship between carbide structure and the position of the metal in the periodic system, which may be represented as shown in Fig. 2.

Chromium (and to a less definite extent manganese) occupies a singular position, in that each of its three carbides has a structure of the same symmetry as, though not identical with, one of the three types : $Cr_{23}C_6$ is cubic (complex face-centred cube with 116 atoms per unit cell), Cr_7C_3 hexagonal, and Cr_3C_2 orthorhombic ; *i.e.*, the metal-richest carbide of chromium simulates class 1, the intermediate one class 2, and the carbon-richest one class 3. This transitional position of chromium is reflected in the part it plays as an alloying element in steels, where the metal is liable to be partitioned between a ferrite (or austenite) solid solution, cementite, $Cr_{23}C_6$, or Cr_7C_3, in a manner dependent on heat-treatment, and composition to a more sensitive degree than the other metals, *i.e.*, it is controllable more readily than is the case with either the stronger carbide-formers (*e.g.*, titanium, vanadium, niobium, molybdenum, tungsten), which always tend towards a definite binary or ternary carbide, or with the weaker ones (manganese, iron, cobalt), tending towards matrix solid solutions or cementite formation. This comparative lability of chromium will form an important part in considering the iron–chromium–tungsten (molybdenum)–carbon system below.

The transitional character of chromium already reveals itself to some extent in its two adjacent elements, vanadium and manganese, both of which show ambiguity in their carbide-forming tendencies. As mentioned before, the vanadium carbide has been variously reported as VC, V_4C_3, or V_2C, and the NaCl type of structure holds true for either VC or V_4C_3 as the actual composition. Assuming, with Desch, V_4C_3 to be correct, this means the progressive fall in carbon/metal in the following order :

Titanium : TiC, 1 carbon to 1 metal atom in NaCl type of carbide.
Vanadium : V_4C_3, 1 carbon to 1¼ metal atoms in NaCl type of carbide, with vacant lattice sites.
Chromium : $Cr_{23}C_6$, 1 carbon to approximately 4 metal atoms in complex face-centred cube.

Manganese has been conflictingly reported to form either Mn_3C of cementite structure or $Mn_{23}C_6$ and Mn_7C_3 of the same structure as their chromium analogues. In fact, both views might be correct, dependent on whether impurities or heat-treatment in the observers' experiments caused a predisposition towards an iron carbide or a chromium carbide formation.

The reason for the above relation of carbide structure with the periodic system must be sought in Hägg's laws connecting the interstitial structures of hydrides, borides, carbides, and nitrides,[61] with

the radius ratio of the non-metal/metal atom. If this ratio does not exceed a certain value, approximately 0·59, the lattices of metal atoms are simple, *i.e.*, cubic or hexagonal close-packed, both with co-ordination number 12; if it exceeds this value, complex structures arise. In the cubic close-packed structures the carbon atoms can occupy either the tetrahedral or the octahedral positions between the metal atoms to conform with either the NaCl or the ZnS type of structure. The lattice is, however, stable even with only partial occupation, so that solid solutions are liable to occur. In both the hexagonal and the cubic close-packed (metal) structures, carbon atoms can be introduced to have the maximum co-ordination number, *viz.*, into those positions in which they occupy the largest space possible, concomitant with the condition that there must be contact between the non-metal and the surrounding metal atoms. The co-ordination number of non-metal atoms in normal interstitial structures is either six or four, depending on the type of position occupied.

The atomic radius r_M of the relevant elements and the radius ratios for the carbides are shown in Table II. The value for the carbon atom may be taken either as that in the diamond, $r_C = 0{\cdot}77$ kX, or, as in the case of the sodium chloride type of structures, the difference $\frac{1}{2}a_0 - r_M$, assuming that the carbon atoms truly occupy the octahedral and no other positions. The latter value would, by definition of the atomic radius, be the sounder one, but in general the location of the carbon atoms in the heavy metal lattice cannot be taken as sufficiently certain from the prevalent structure determinations, as the line intensities depend almost entirely on the metal lattice, and the carbon positions have mainly been deduced from their indirect effect on the metal configuration. For the compounds of the NaCl type of structure it was of interest to compare the observed cube-edges, using the best available data, with those calculated as the sum of Goldschmidt's atomic diameters, and $r_C = 0{\cdot}77$ kX (diamond). Table II shows that the divergence is quite appreciable, the observed value being the smaller throughout. This discrepancy may have several explanations :

(1) Some carbon positions are left vacant, the formula MC not being strictly correct.

(2) Partial ionization exists, implying that the bonding, *e.g.*, in TiC, is not simply a metallic one with interstitial metalloids, but that it tends towards an ionic compound.

(3) The carbon positions are not necessarily the octahedral ones, but are displaced, *e.g.*, in a tendency to produce the ZnS rather than the NaCl type of structure.

Explanation (1) appears to be the most probable, in view also of the observed differences in composition of the compounds (atomic metal/carbon ratio $> 50\%$). The correctness of Hägg's rule is, however, clearly shown in Table II, *i.e.*, for the close-packed cubic and hexagonal carbides of titanium, zirconium, vanadium, niobium, tantalum, molybdenum, and tungsten, the radius ratios fall below 0·59, for the more complex ones of chromium, manganese, and iron, above 0·59. The relationship between structure of carbides and the periodic table is therefore linked with the variation of atomic size as a function of atomic number, though other factors enter as well.

Interrelation of Carbides

Referring again to Fig. 2, the carbide structures of lowest symmetry (orthorhombic) are the least stable. Iron can, however, form an integral part of ternary, more stable carbides. On reviewing the available data (given in a later section on ternary systems), the following rules apply :

(1) In conjunction with metals belonging to class 1 (*i.e.*, those which form cubic carbides), iron forms no ternary carbides nor solid solutions ; the available carbon is tied up by these metals.

(2) In conjunction with metals belonging to class 2 (*i.e.*, those which form hexagonal carbides), iron does form ternary carbides which themselves are cubic, and have a limited solubility for iron (*viz.*, Fe_3W_3C/Fe_4W_2C, Fe_3Mo_3C/Fe_4Mo_2C).

(3) In conjunction with the metal-forming transitional carbides (chromium), no ternary carbides are formed, but the primary carbides of both iron and chromium possess considerable mutual solubility.

Table II

ATOMIC RADIUS RATIOS IN CARBIDES

Metal	Atomic Radius r_M for 12 Co-ordination*	Lattice Dimensions (a_0) for Unit Cube			r_C/r_M, Assuming r_C:	
		Observed	Theoretical‡	Divergence, %	= 0·77 (Diamond)	= $\frac{1}{2}a_0 - r_M$
Cubic carbide: Titanium	1·46	4·3251[43]	4·46	+ 3	0·53	0·48
Zirconium	1·60	4·687[51]	4·74	+ 1	0·48	0·46
Hafnium	...	...	...	...	...	...
Vanadium	1·35	4·152[35]	4·24	+ 2	0·57	0·54
Niobium	1·47	4·440$_4$†	4·48	+ 1	0·52	0·51
Tantalum	1·47	4·445[51]	4·48	+ 1	0·52	0·51
Transition carbide: Chromium	1·28	...	...	...	0·60	...
Hexagonal carbide: Molybdenum	1·40	...	...	...	0·55	...
Tungsten	1·41	...	...	...	0·55	...
Orthorhombic carbide: Manganese	1·29 (in γ-Mn)	...	...	...	0·60	...
Iron	1·26 (in γ-Fe)	...	...	...	0·61	...

* V. M. Goldschmidt's values † Observed by the author ‡ As $a_0 = 2(r_M + 0{\cdot}77)$

(4) In conjunction with the metals belonging to class 3 (*i.e.*, those which form the orthorhombic carbides Mn_3C, Co_3C, Ni_3C), iron forms its own carbide (cementite), which is isomorphous and completely intersoluble with the latter. (Manganese is liable, however, to play a double rôle and to simulate a transitional carbide-former, in which case a ternary carbide may occur.)

These rules are of direct application to the understanding of the iron–chromium–tungsten (molybdenum)–carbon system, to be dealt with later. In a generalized form (and applied with due caution) they may help to predict compound formation in other steel systems, *e.g.*, those involving titanium and niobium. Too few experimental data are, however, available to permit such generalization at present.

Carbides within each structure class are liable to show complete or partial intersolubility, depending largely on whether the atomic size factor is favourable or not. For instance, the systems TaC–NbC and TiC–TaC show continuous solid solutions at all temperatures, while others do so only at high temperatures, segregation taking place on cooling (*e.g.*, W_2C–TaC[34]). The same is true for the system tungsten-carbide/titanium-carbide, recently examined by Metcalfe[42] as the basis of hard-metals. It has been shown by Brownlee and co-workers[59] that at 2000° C. TiC dissolves up to 75% of WC, at 1500° C. 45% of WC, while for lower temperatures a rapid fall of solubility occurs. On the other hand, no intersolubility occurs, *e.g.*, in the system W_2C–ZrC.[62] These observational facts can, in many cases, be related to the atomic sizes shown in Table II, *e.g.* :

	Difference in Size of Metal Atom, %	Solubility
TaC–NbC	0	Continuous
TiC–TaC	1	Continuous
W_2C–TaC	4	Continuous at high temp., partial at low temp.
TiC–WC	3·5	Partial
W_2C–ZrC	13	Nil

There are, however, certain solubility data available, *e.g.*, those of Molkov and Vicker,[63] which show that the atomic size factor is by no means the only governing one, and that valency and other factors enter as well. According to Agte and Altherthum[50] TaC–ZrC and TaC–HfC also form continuous series of solid solutions, though the zirconium atom is exceptionally large. (No information is available regarding hafnium.) The stoichiometric ratio of carbon/metal in the carbide end members naturally has a considerable influence, and the mutual replaceabilities of metal atoms in a given structure depend on whether the distribution of interstitial carbon atoms prevailing in the first compound leaves sufficient space for the foreign metal atoms to be accommodated. There are cases, of which the system Fe_3C–$Cr_{23}C_6$ is an example (*cf.* later), in which a different type of carbon bonding is favoured by the solute atom, even though substitution still takes place (*e.g.*, to favour a tetrahedral rather than an octahedral carbon configuration), so that in effect the stoichiometric ratio is bound to alter even within an apparent isomorphous series of solid solutions ; the series is strictly not isomorphous as far as the carbon distribution is concerned, though it would appear so from the X-ray pattern.

Nitrides, borides, hydrides, and some oxides should also be referred to in this connection, because of their isomorphy and solubility relations with the carbides ; *e.g.*, the system TaC–TaN forms a complete series of solid solutions,[64] and so does TiC–TiN (Hume-Rothery[43]). A practical example of the application of these principles may here be mentioned.

X-ray analysis of the electrolytic carbide extract from a titanium-bearing austenitic steel showed two phases, each of the NaCl type of structure. They corresponded to a nitrogen solid solution in TiC and a carbon solid solution in TiN ; from the parameters the amounts of mutual replacement were estimated as follows :

Compound	Amount, %	Lattice Parameter, kX Hume-Rothery	Present Author	Solid Solution*
TiC, pure	...	4·325	...	...
$Ti(C,_N)$	70	...	4·3245	0·65% N in TiC
$Ti(N,_C)$	30	...	4·2419	9·6 % C in TiN
TiN, pure	...	4·2330	...	...

* Assuming the validity of Vegard's law.

Small white flakes in the extracted powder were found to contain segregates of nitride, *viz.*, 65% $Ti(N,_C)$ 35% $Ti(C,_N)$, around silica particles. Evidently melting and cooling conditions had not permitted equilibrium to be reached, otherwise a single-, not two-phase, solid solution would have appeared. The compound referred to by metallurgists as " cyanonitride " is thus not a real compound, but consists of primary solid solutions. Figure 3 shows photometer records illustrating variations in amounts.

A point shown by this example well illustrates the structure rules of carbides in steels formulated above. The steel can be obtained in either an austenitic or a ferritic condition, and on X-ray analysis the carbide extracts showed the following constituents :

Ferritic	Austenitic
$Ti(C,_N)$	$Ti(C,_N)$
$Ti(N,_C)$	$Ti(N,_C)$
$(Cr,Fe)_{23}C_6$	No further phase

Thus the only compounds associated with the austenitic condition are the cubic close-packed ones

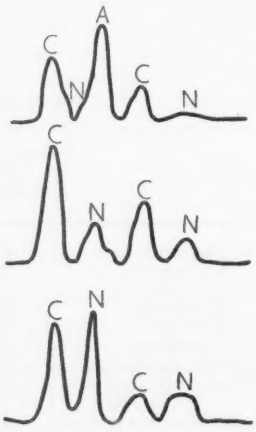


Fig. 3—Photometer records illustrating variations in amount of austenite (*A*), carbide TiC (*C*), and nitride TiN (*N*) in residues from titanium-bearing steel

(class 1) of titanium ; any carbon in excess of the amount which can be tied up by the available titanium appears in austenitic solution. In the ferritic condition, on the other hand, with its low matrix solubility for carbon, the extra carbon which has now been freed, and no longer finding any class 1 element available, forms the complex cubic chromium carbide as structurally the nearest approach to class 1.

THE STRUCTURES OF $Cr_{23}C_6$, Fe_4W_2C, AND Fe_3C

The structures of the three carbides $Cr_{23}C_6$, Fe_4W_2C, and Fe_3C, are of special relevance in considering the iron–chromium–tungsten (molybdenum)–carbon alloys, and will here be briefly compared.

The unit cell of $Cr_{23}C_6$ is shown in Fig. 4, of Fe_4W_2C in Fig. 5, and of cementite in Fig. 6. Table III summarizes the chief data on atomic distribution and distances ; Cr_7C_3 and the two tungsten carbides are also included.

$Cr_{23}C_6$ and Fe_4W_2C

Westgren and his collaborators have determined the structures of $Cr_{23}C_6$ and Fe_4W_2C. [31, 65]

The two cubic unit cells have the cube edge 10·64 and 11·04 kX for $Cr_{23}C_6$ and Fe_4W_2C respectively ; there are 92 and 96 atoms per unit cell. Subdividing each into eight cubes, the corners of these are alternately surrounded in $Cr_{23}C_6$ (Fig. 4) by cubo-octahedra and cubes, and in Fe_4W_2C (Fig. 5) by octahedral units and tetrahedral ones. The octahedra are randomly occupied by tungsten and iron, the tetrahedra by iron. In $Cr_{23}C_6$ a further metal atom is placed at the centre of each eighth cube (*c* positions) ; these are significant as being those occupied by any tungsten in solution. A limit to the capacity of this carbide to dissolve tungsten is thus set, because any tungsten in excess of 8 out of 92 would find no room in the structure ; the phase-change $(Fe,W,Cr)_{23}C_6 \rightarrow Fe_4W_2C$ is then brought about, consisting of the rearrangement of the cubo-octahedral and cubic units to form the plain octahedral and tetrahedral ones of Fe_4W_2C. (*N.B.*—It would be mistaken to attribute to these units anything but geometrical meaning ;

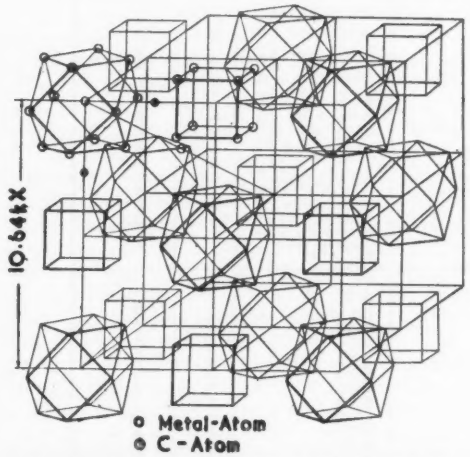


Fig. 4—Unit cell of carbide $(Cr,Fe,W,Mo)_{23}C_6$

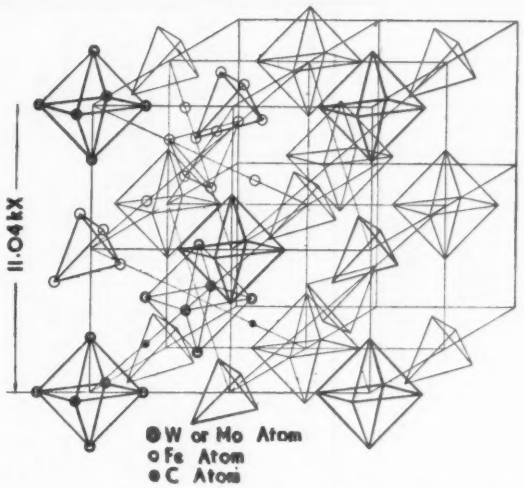


Fig. 5—Unit cell of carbide $Fe_4(W,Mo)_2C$ $Fe_3(W,Mo)_3C$

they are not molecular " clusters " in the physical sense, but are convenient to describe the structure.) In $Cr_{23}C_6$ the chromium can be replaced by iron up to approximately 30%, whence onwards the presence of some tungsten is necessary in the lattice in order to enable it to dissolve more iron ; without this tungsten the $(Cr,Fe)_{23}C_6$ structure becomes unstable and cementite would be formed instead. This can be explained on the grounds that the substitution of chromium by iron in $Cr_{23}C_6$ is not entirely random, but that the cubic (*f*) positions are occupied preferentially by iron atoms. Since the iron atom is of smaller size than chromium (diameter 2·52 as against 2·57 kX), too much space becomes available at the (*c*) positions for them to continue taking either iron

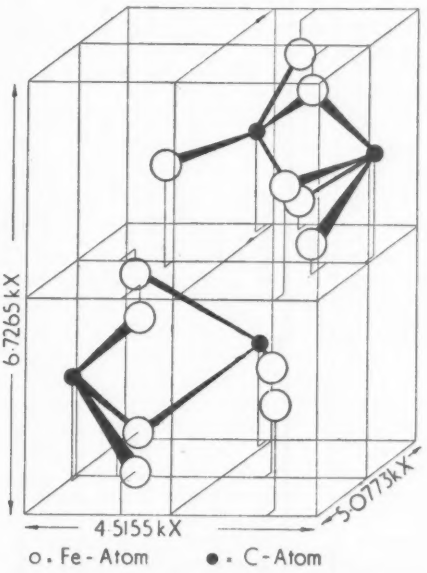


Fig. 6—Unit cell of cementite Fe_3C

Table III

COMPARISON OF STRUCTURES OF Fe_3C, $Cr_{23}C_6$, Fe_4W_2C, Cr_7C_3, AND WC/W_2C (SALIENT FEATURES)

	Cementite, Fe_3C	$Cr_{23}C_6$–$Fe_{21}W_2C$	Fe_4W_2C	Cr_7C_3	WC	W_2C
Symmetry	Orthorhombic	Cubic	Cubic	Hexagonal (trigonal)	Hexagonal	Hexagonal
Space Group	Pbnm	Fm 3 m	Fd 3 m	C_{3v}^4	..	..
Unit Cell Dimensions	$a = 4{\cdot}5144$, $b = 5{\cdot}0787$, $c = 6{\cdot}7297$ kX	$a_0 = 10{\cdot}638 - 10{\cdot}51$ kX	11·04 kX	$a = 13{\cdot}98$, $c = 4{\cdot}523$ kX	$a = 2{\cdot}94$, $c = 2{\cdot}86$	$a = 2{\cdot}99$, $c = 4{\cdot}72$ kX
Volume of Unit Cell	154 kX^3	1204 – 1160 kX^3	1340 kX^3	489 kX^3	approx. 64·2 kX^3	105 kX^3
Number of Atoms per Unit Cell	16 = 12 Fe, 4 C	116 = 92 metal, 24 C	112 = 96 metal, 16 C	80 = 56 metal, 24 C	12 = 6 W, 6 C	9 = 6 W, 3 C
Atomic Parameters	8 Fe at $x = 0{\cdot}333$, $y = 0{\cdot}183$, $z = 0{\cdot}065$ (*a* positions) 4 Fe at $u = \overline{0{\cdot}167}$, $v = 0{\cdot}040$ (*b* positions) 4 C at $u_1 = 0{\cdot}47$, $v_1 = \overline{0{\cdot}14}$ (*c* positions)	4 Cr at 000 (*a* positions) 32 Cr at uuu, $\bar{u}\bar{u}u$, $\bar{u}u\bar{u}$, $u\bar{u}\bar{u}$, $\bar{u}\bar{u}\bar{u}$, $\bar{u}uu$, $u\bar{u}u$, $uu\bar{u}$; $u = 0{\cdot}385$, $v = 0{\cdot}165$, $w = 0{\cdot}275$ (*f* positions) 8 Cr at $\frac{1}{8}\frac{1}{8}\frac{1}{8}$, $\frac{3}{8}\frac{3}{8}\frac{3}{8}$ (*c* positions) 48 Cr at $v\bar{v}0$, $0v\bar{v}$, $\bar{v}0v$, $vv0$, $0vv$, $v0v$, $\bar{v}\bar{v}0$, $0\bar{v}\bar{v}$, $\bar{v}0\bar{v}$, $\bar{v}v0$, $0\bar{v}v$, $v0\bar{v}$ (*h* positions) 24 C at $w00$, $\bar{w}00$, $0w0$, $0\bar{w}0$, $00w$, $00\bar{w}$ (*e* positions)	16 Fe at $\frac{1}{8}\frac{1}{8}\frac{7}{8}$, $\frac{1}{8}\frac{7}{8}\frac{1}{8}$, $\frac{7}{8}\frac{1}{8}\frac{1}{8}$, $\frac{7}{8}\frac{7}{8}\frac{7}{8}$ (*d* positions) 32 Fe at uuu, $\frac{1}{4}-u\ \frac{1}{4}-u\ \frac{1}{4}-u$, $u\bar{u}\bar{u}$, $\frac{1}{4}-u\ \frac{1}{4}-u\ u+\frac{1}{4}$, $\bar{u}uu$, $u+\frac{1}{4}\ \frac{1}{4}-u\ u+\frac{1}{4}$, $uu\bar{u}$, $u+\frac{1}{4}\ u+\frac{1}{4}\ \frac{1}{4}-u$; $u = -0{\cdot}175$, $v = 0{\cdot}195$ (*e* positions) 32 W and 16 Fe randomly distr. at $v00$, $\frac{1}{2}-v\ \frac{1}{2}\ \frac{1}{2}$, $\bar{v}00$, $v+\frac{1}{2}\ \frac{1}{2}\ \frac{1}{2}$, $0v0$, $\frac{1}{2}\ \frac{1}{2}-v\ \frac{1}{2}$, $0\bar{v}0$, $\frac{1}{2}\ v+\frac{1}{2}\ \frac{1}{2}$, $00v$, $\frac{1}{2}\ \frac{1}{2}\ \frac{1}{2}-v$, $00\bar{v}$, $\frac{1}{2}\ \frac{1}{2}\ v+\frac{1}{2}$ 16 C at $\frac{1}{8}\frac{1}{8}\frac{1}{8}$, $\frac{1}{8}\frac{3}{8}\frac{3}{8}$, $\frac{3}{8}\frac{1}{8}\frac{3}{8}$, $\frac{3}{8}\frac{3}{8}\frac{1}{8}$ (*c* positions)	2 Cr at $\frac{1}{3}\frac{2}{3}u$, $\frac{2}{3}\frac{1}{3}u+\frac{1}{2}$ 54 Cr + 24 C at 13 positions: rst; $s-r$, r, t; s, $r-s$, t; s, r, $t+\frac{1}{2}$; r, $s-r$, $t+\frac{1}{2}$; $r-s$, s, $t+\frac{1}{2}$ Parameters not finally determined	W at 000 C at $\frac{1}{3}, \frac{2}{3}, \frac{1}{2}$	W at $\frac{2}{3}, \frac{1}{3}, \frac{1}{4}+0{\cdot}02$ C at 00
Environment: Number and Distances (kX) of Neighbouring Atoms	8 Fe at (*a*): 11 neighbours: 1 at 2·49, 2 at 2·51, 1 at 2·52, 1 at 2·54, 1 at 2·55, 2 at 2·62, 1 at 2·67, 4 at 2·68 4 Fe at (*b*): 12 neighbours: 2 at 2·52, 2 at 2·54, 2 at 2·65, 2 at 2·67, 4 at 2·68 4 C at (*c*): 6 neighbours: 1 at 1·85, 1 at 1·89, 2 at 2·06, 2 at 2·5 kX	4 Cr at (*a*): 12 neighbours: at 2·49 8 Cr at (*c*): 4 at 2·49, 12 at 2·95 32 Cr at (*f*): 1 Cr at 2·49, 3 Cr at 2·45, 6 Cr at 2·74, 3 C at 2·10 48 Cr at (*h*): 1 Cr at 2·49, 4 Cr at 2·51, 6 Cr at 2·74, 8 Cr at 2·95, 2 C at 2·10 24 C at (*e*): 8 Cr at 2·10	16 Fe at (*d*): 6 Fe at 2·34, 6 W (Fe) at 2·79, 32 Fe at (*e*): 6 Fe at 2·34, 6 W at 2·74, 3 W at 2·79 32 W and Fe at (*f*): 4 Fe at 2·74, 2 Fe at 2·79, 2 W at 2·92, 4 W at 3·05, 2 C at 2·10 16 C at (*c*): 6 W (Fe) at 2·10		Each W: 6 W at 2·94 6 C at 2·22 Each C: 6 W at 2·22 6 C at 2·86	Each W: 9 W at 2·78 3 C at 2·15 Each C: 6 W at 2·15 6 C at 2·99
Shortest Distances, kX	Fe–Fe = 2·49; Fe–C = 1·85	Cr–Cr = 2·49; Cr–C = 2·10	Fe–Fe = 2·34; Fe–W = 2·74; W(Fe)–C = 2·10		W–W = 2·94 W–C = 2·22 C–C = 2·86	W–W = 2·78 W–C = 2·15 C–C = 2·99
Atomic Substitution	Fe probably randomly replaceable by Cr	In $Fe_{21}W_2C$, W occupies the 8 (*c*) positions, Fe the 84 (*a*, *f*, and *h*) positions	Fe–W randomly replaceable in 48 (*f*) positions between Fe_4W_2C and Fe_6W_2C			

or chromium, and from one critical composition onwards the larger tungsten or molybdenum atom* is required to fill them (atomic diameter 2·82 and 2·80 kX). It is observed in practice that the "detachment" in the iron–chromium–tungsten–carbon system of the $Cr_{23}C_6$ single-phase field from the ternary side iron–chromium–carbon occurs at approximately 30 at.-% of iron, which is the same proportion as available (f) sites, *viz.*, 32 out of 92 = 35% of iron. The agreement is within the error of known data, but is not bound to be exact, since some replacement by tungsten might be expected to begin already before all cubic positions are filled by iron. Similarly, as Westgren has pointed out, with adequate tungsten supply, chromium can be entirely replaced by iron in $Cr_{23}C_6$, and the proportion of tungsten to achieve this is defined by the proportion of available (c) positions, *i.e.*, 8 out of 92, which gives rise to the formula $Fe_{21}W_2C_6$.

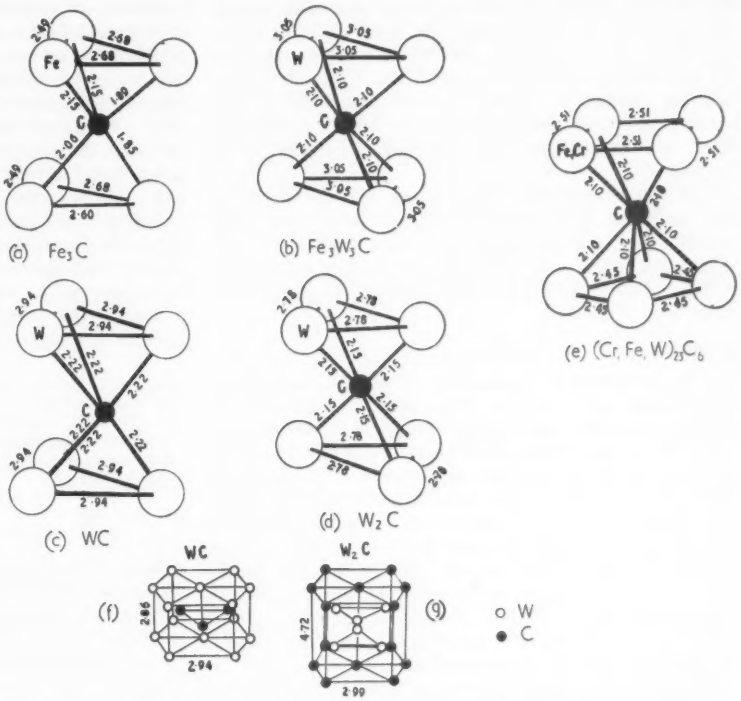


Fig. 7—(*a*)–(*e*) Carbon environment in carbides of iron, chromium, and tungsten; (*f*) and (*g*) unit cells of WC and W_2C

Carbon Environment

In $(Cr,Fe,W)_{23}C_6$ the carbon atoms occupy positions on the cube edges between the cubo-octahedra and cubes, each carbon having eight metal neighbours. In Fe_4W_2C, on the other hand, they lie between the two tungsten octahedra, on the cube diagonal, each carbon atom being itself surrounded by the slightly distorted octahedron bounded by two faces of the regular tungsten octahedra (*cf.* Fig. 5). There are thus six neighbours to each carbon. It is interesting to note that this carbon environment in Fe_4W_2C is already identical with that in tungsten carbide W_2C; in both cases the surrounding tungsten configuration is that of two isosceles triangles inverted. The fact that in the Fe_4W_2C structure the carbon atoms should choose to surround themselves entirely with tungsten, not iron, atoms is noteworthy as indicating a stage preliminary to the formation of tungsten carbide. In cementite the metal environment of carbon is also six-fold, but it consists of two congruent, not inverted, triangles (prism, as shown in Fig. 7 (*a*)) (Lipson[21]). These two types of six-fold co-ordination (*viz.*, *A* that of congruent, and *B* that of inverted triangles) are of considerable interest because this difference recurs in the plain tungsten carbides. The two carbides W_2C and WC, which are both of hexagonal structure, differ in so far as in WC the tungsten and the carbon atoms each form a set of interpenetrating simple hexagonal lattices, whereas in W_2C the tungsten atoms form an almost *close-packed* lattice, the carbon atoms a *simple* hexagonal lattice (*see* Figs. 7 (*f*) and 7 (*g*)). Thus the repeat of close-packed atomic sheets in the *c* direction is :

In WC : W —— C —— W —— C —— W, etc.
In W_2C : W — W′ — C — W — W′ — C, etc.
(where W and W′ signify layers of tungsten atoms rotated through 30° to arrive at close-packing†).

The carbon environment of the two tungsten carbides is thus also that of a 6-co-ordination, the metal neighbours being related to the carbon atom in the two distinct manners (types *A* and *B* above) found in cementite and Fe_4W_2C respectively. The following is a summary of the environments :

Carbide	Environment of C-atom: Co-ordination	Configuration
Cementite Fe_3C	6	Type *A* (congruent triangles)
$(Cr,Fe,W)_{23}C_6$	8	Transition type (squares on either side of carbon)
Fe_4W_2C	6	Type *B* (inverted triangles)
WC	6	Type *A*
W_2C	6	Type *B*

Thus in the iron–chromium–tungsten–carbon system (and this principle may extend to others) the metal environment to the carbon atom in the carbides occurring is repeated for entirely different carbide compositions, but changes from the congruent type *A* to the inverted type *B* with increasing metal/carbon ratio. The carbide $(Cr,Fe,W)_{23}C_6$ is abnormal in

* Molybdenum throughout the present argument may replace tungsten.

† For further comment, *see* later section (p. 357).

showing 8- instead of a 6-co-ordination and, being intermediate in composition to Fe_3C and Fe_4W_2C, appears to have adopted this 8-fold environment as a compromise between the two 6-fold types, but it is queried whether in Westgren's structure (Fig. 5) the carbon positions shown should be finally accepted. Their re-examination by accurate photometry is suggested.

The reason why the carbon content decreases in the carbides Fe_3C–$(Cr,Fe,W)_{23}C_6$–Fe_4W_2C (in this order), also follows from an examination of the structures (Figs. 4–6), since the number of equivalent lattice points available for carbon becomes progressively less.

Cementite and $(Cr,Fe,W)_{23}C_6$

The structure of cementite, shown in Fig. 6 (*cf.* also Table III), consists of a complex network of slightly distorted triangular prisms of iron atoms, with the carbon atoms placed approximately centrally so as to possess six iron neighbours. It has been discussed by Lipson and Petch[21] (who re-determined it), Hume-Rothery,[22] and Petch,[23] *e.g.*, to discover its relation to austenite and ferrite. These papers may be referred to for details. In practice it is found that with only slight differences in heat-treatment and composition of low chromium, tungsten, and molybdenum steels, it is possible to produce $(Cr,Fe,W,Mo)_{23}C_6$ instead of cementite.

Experiments show that for a given steel (6% of chromium and 1·1% of carbon) cementite can be produced by quenching from the austenitic region, while $(Cr,Fe)_{23}C_6$, cementite, or $(Cr,Fe)_7C_3$ can be precipitated on annealing at a subcritical temperature, depending on the high-temperature history previous to the anneal ; it is therefore considered worth while to search for any structure relationship. Hume-Rothery has shown that by a comparatively simple shear mechanism it is possible to obtain the cementite lattice from that of martensite, and thus claims a closer relationship of cementite to the body-centred than to the face-centred cubic lattice. (Actually the argument has become affected by Lipson and Parker's subsequent structure determination of martensite, showing the carbon positions to lie on the tetragonal *c* edges, and on two basal planes of the tetragonal unit cell, not at the face-centres as assumed by Hume-Rothery ; but, being based on displacements of the metal, not the carbon atoms, it still remains essentially valid.) On the other hand, as the co-ordination of each iron atom in cementite is approximately 12, the structure is nearly close-packed in common with austenite.

The carbide $(Cr,Fe)_{23}C_6$ is related to austenite and martensite in a remarkable manner. The cubo-octahedra (Fig. 4) (Westgren's *h* positions) which form an integral unit of repeat in this carbide, are, in fact, the simplest possible compromise between a face-centred and a body-centred cube. They may be considered as a face-centred cube in which the atoms *F* at the face-centre have been " forced outward " by the insertion of an atom *B* at the body-centre, so as to render all atoms equidistant from the latter. The body-centred cube is already present as part of the cubo-octahedron, as is apparent from Fig. 4. By the insertion or removal of one atom *B*, a ferrite-like or austenite-like unit can thus be arbitrarily produced, which is the one occurring in this carbide. It involves the majority (52 out of 92) of its metal atoms, the simple cubic units (*f* positions) alternating with the cubo-octahedra and the 8 (*c*) atoms ; it may be noted that by the simple device of placing the (*c*) atoms inside the *f* cubes, instead of outside, a body-centred cube is obviously produced, similar to that already existing in the cubo-octahedra. The total number of available *f* and *c* atoms (32 and 8) is just the correct one for this operation and accounts for all remaining metal atoms.

Expressed briefly, the carbide structure (metal atoms) is composed as follows :

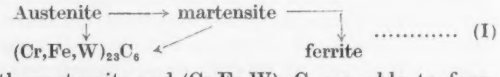
Unit	Atoms Involved (number and position)	Operation Producing this Unit
Cubo-octahedra (" Hybrid " between body-centred and face-centred cube)	48 (*h*) and 4 (*a*)	Insert one atom into face-centred cube
Simple cube	32 (*f*)	Remove one atom from body-centred cube
Single atom (*c*)	8 (*c*)	
	(Total 92)	

(These " operations " are not, of course, real ones occurring during the formation of the carbides, but are hypothetical and are intended to bring out the relationship with austenite and ferrite.)

It is significant that the 8 (*c*) positions are those filled by the larger tungsten or molybdenum atoms, when present, which would find no room inside the cube, but do so outside.

The carbon atoms in $(Cr,Fe,W)_{23}C_6$ are placed interstitially between the cubo-octahedra and the simple cubes, as against their known positions in austenite at the centre of the face-centred cube. The insertion of the extra metal atom (*a*) into the face-centred cube (to form the cubo-octahedra) has clearly made it impossible for it to retain a position corresponding to austenite, so that it has become " displaced " outside this unit, giving the carbide its characteristic structure.

It is considered on the above grounds that the structure relation between this carbide and both austenite and ferrite is sufficiently close for visualizing that the carbide lattice is formed as a stable alternative to martensite during the decomposition of austenite. It is characteristic that, *e.g.*, in certain austenitic and semi-austenitic heat-resisting steels, the carbide $(Cr,Fe,W)_{23}C_6$ is the one coexisting with and precipitating from austenite at high temperatures, while at lower temperatures the following transformation takes place :



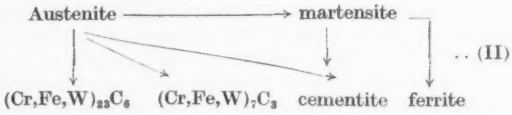
..... (I)

Both martensite and $(Cr,Fe,W)_{23}C_6$ are able to form from austenite by a spontaneous transformation of the lattice, not involving atomic diffusion and therefore proceeding instantaneously. The partition of atoms between the metastable martensite and the stable carbide at any one stage of heat-treatment must be decided by free-energy considerations ; it seems probable that a saturation solid solution of carbon in parent austenite will favour a collapse into

the carbide, a lower carbon content one into martensite.

Considering the formation of cementite in ferritic low-chromium steels as an observed alternative to $(Cr,Fe,W)_{23}C_6$, it follows that the atomic rearrangement in the form of the cementite tetrahedral units offers itself as a third possibility. Since cementite occurs in the quenched state together with martensite, $(Cr,Fe,W)_{23}C_6$ in the annealed state together with ferrite, it appears that the latter carbide is the truly stable one (for the given composition), but that it is easier spontaneously to produce the cementite and martensite lattices as metastable intermediate stages. $(Cr,Fe,W)_7C_3$ is found, for the same composition, to be a fourth possible structure formed by low-temperature heat-treatment, probably as a metastable product.

The previous set of reactions (I) or the following set (II) may therefore occur :



.. (II)

The existence in the quaternary phase diagram of the tongue-shaped $(Cr,Fe,W)_{23}C_6$ field detaching itself from the ternary iron–chromium–carbon side at approximately 30% of iron and joining to $Fe_{21}W_2C_6$, shows that set (I) is favoured for high-chromium contents, but also for lower ones, provided that sufficient tungsten is present, while set (II) is favoured by low-alloy steels, though, to form $(Cr,Fe,W)_7C_3$, sufficient chromium will have to be present.

An examination of the structures of cementite and $(Cr,Fe,W)_{23}C_6$ does not reveal any simple relationship, and it is probably not advisable to attempt deriving one directly from the other, but to relate each to either austenite or martensite, or both, and to consider them as independent and alternative arrangements. The same applies to $(Cr,Fe,W)_7C_3$.

Equivalent Unit Cells

It may, however, be of interest to point out one relation between the carbide structures based on volume considerations.

If 8 orthorhombic unit cells of cementite, each containing 16 atoms, are stacked together, this enlarged volume of $(2 \times 4{\cdot}51) \times (2 \times 5{\cdot}08) \times (2 \times 6{\cdot}73) = 1234$ kX³ forms an aggregate directly comparable with and equivalent to one unit cell of $(Cr,Fe,W)_{23}C_6$ and of Fe_4W_2C. The formulæ of the three carbides thus are :

	Equivalent Volume, kX³
$M_{96}C_{32}$ (= cementite)	1234
$M_{92}C_{24}$ (= $(Cr,Fe,W)_{23}C_6$)	1204 to 1160 (for $Cr_{23}C_6$ and $Fe_{21}W_2C_6$)
$M_{96}C_{16}$ (= Fe_4W_2C)	1346

In each carbide 96 metal atoms (except for four missing in one) fill, with their carbons, an integral number of cells with a volume of the same order of magnitude ; these form " elementary bricks " on which a study of carbide relations in steels may usefully be based. The fact that the number of carbon atoms associated with these 96 (92) metal atoms decreases as 32/24/16 with increasing W : (Fe + Cr) ratio follows naturally from the places they occupy and space considerations in each lattice (*cf.* above) and strongly suggests that the series of compounds

$$Fe_{96}C_{32} - (Fe,W)_{92}C_{24} - Fe_{48}W_{48}C_{16} - \text{tungsten metal}$$

(with some latitude for solid solutions) forms a pseudo-binary system, in which the formation of further stable structures with intermediate carbon contents is quite possible (*e.g.*, a hypothetical tungsten-rich carbide $(Fe,W)_{96}C_8$). This pseudo-binary character of the series falls into line with experimental results given later.

Possibility of Lattice-Fault Formation in Tungsten Carbides

A point arose out of the above discussion on tungsten carbide structures which requires some expansion. There is an analogy between W_2C and WC on the one hand, and the two crystalline forms of graphite, reported by Lipson and Stokes,[66] on the other. In ordinary graphite (α) the hexagonal close-packed sheets of carbon atoms repeat every alternate layer, and in the second type (β), every third layer. In WC and W_2C the same difference applies, the repeat of close-packed tungsten and carbon layers being as follows :

000 | $\frac{1}{3}\ \frac{2}{3}\ \frac{1}{2}$ | 000 | $\frac{1}{3}\ \frac{2}{3}\ \frac{1}{2}$, etc., in WC and α graphite
000 | $\frac{1}{3}\ \frac{2}{3}\ \frac{3}{4} - \delta$ | $\frac{2}{3}\ \frac{1}{3}\ \frac{1}{4} + \delta$ | 000, etc., in W_2C and β graphite
($\delta = 0$ in graphite, but represents a small displacement from the ideal positions equal to 0·02 in W_2C.)

In hexagonal cobalt Edwards and Lipson[67] have found the phenomenon of " fault formation," *i.e.*, the existence of imperfections in the stacking of lattice planes. This consists of irregularities in the period of repeat of the close-packed cobalt layers in which the sequence of packing is liable to change from the type *ABABAB*, etc., to *BCBCBC*, etc. (in the direction of the hexagonal axis). In the tungsten carbide structure conditions are favourable for similar " faults " to occur, and if it is true that WC and W_2C are partly intersoluble, such faults must necessarily occur during the transition $WC \longleftrightarrow W_2C$. It appears probable that hardness and other properties of the tungsten carbides will be considerably affected by fault formation. If pure WC and pure W_2C have the ideal layer lattices, as in graphite, easy slip and therefore reduced hardness might be expected in the direction parallel to the hexagonal basal planes, but it would require only a small amount of excess tungsten in WC or of excess carbon in W_2C in order to destroy this anisotropy, by introducing sufficient imperfections in the manner of stacking.

This would have a considerable bearing on the properties of hard-metal tool materials, since cracking and weakness may well be caused by external contacts (*e.g.*, during pressing or under the influence of the material worked by the tool in operational practice). Remembering that cobalt metal is commonly used as the binder to tungsten carbide in tool tips, it may be relevant to note that both share the close-packed structure and the inherent liability to form Lipson-type faults, which, during the mixing and sintering process, may produce special conditions of diffusion and adhesion at the cobalt–carbide interface.

The existence of fault formation corresponds to the simulation of the diamond structure within small regions of the tungsten carbide lattice. In the case of β graphite, this has already been pointed out by Lipson and Stokes. In diamond, the graphite planes become puckered, a condition which also applies here and produces points of interlocking of the layers. Becker[56, 57] has already noted that in tungsten carbides the carbon assumes the atomic volume of diamond, and attributes their great hardness to this fact.

TERNARY CARBIDES

The literature on ternary systems having iron–carbon as a base is very extensive, and a brief summary, partly in tabular form, may suffice. Stress is laid on the question of carbides formed, while for the actual phase diagrams reference may be made to the published literature. Carbide systems not involving iron are not covered at present.

Table IV gives the binary and ternary compounds formed in each system and the carbide intersolubilities as far as they are known. The temperature to which this applies is room temperature or the lowest for which information is available (at any rate below 700° C.). Some information on the ternary systems additional to that given in Table IV was thought to be useful, in particular the fields of coexisting phases at low temperatures. This is given in the following paragraphs :

Iron–Nickel–Carbon

Phase-Fields : α (ferrite) sol. sol., α + γ, γ (austenite) sol. sol., α + γ + Fe_3C, α + Fe_3C, γ + graphite.)

The main interest in the diagram is the kinetics of the α–γ transformation, and the link-up of martensite with intermediate stages in iron–nickel alloys. The phase boundaries are not quantitatively certain, owing to sluggish reactions (*e.g.*, Lange and Matthieu[68]).

Kase,[69] Söhnchen, and Piwowarsky,[70] Bain,[71] and Andrew and his collaborators,[72] have also investigated this system ; Dehlinger[73] gives a diagram, which, however, is purely hypothetical.

Iron–Cobalt–Carbon

Phase-Fields (Vogel and Sundermann[74]) : α sol. sol., α + γ, γ sol. sol., α + γ + Fe_3C, α + Fe_3C, γ + graphite.

Iron–Manganese–Carbon

Phase-Fields : α, α + Fe_3C, α + γ + $(Fe,Mn)_3C$, α + γ, γ, γ + $(Fe,Mn)_3C$, $(Fe,Mn)_3C$, β-Mn_3C + $(Fe,Mn)_3C$, β-Mn_3C + γ + $(Fe,Mn)_3C$, β-Mn_3C + γ, α-Mn_3C + γ + α-Mn, α-Mn + α-Mn_3C, γ + α-Mn, α-Mn.

For moderate manganese contents straight ferrite–austenite–$(Fe,Mn)_3C$ equilibria apply. Complexities set in only for more than 50% (approximately) of manganese.

Vogel and Döring[75] and Walters and Wells[76] derived diagrams, those of the latter including the carbide observed is $(Fe,Mn)_3C$ with Fe : Mn ≃ 3 : 1 ; these authors and others discuss the ε-phase and believe it to be unstable, though " persistent," and a product of spontaneous transformation from austenite, as alternative to martensite. Kuznetsov and Evseeva[78] agree with the metastable character of ε. (The ε structure is hexagonal, with $a = 2{\cdot}527$, $c = 4{\cdot}075$ kX.) Gensamer[79] supplements Bain, Davenport, and Waring's diagram. Wever and Matthieu[80] discuss the kinetics of matrix transformations, but state that " different " carbides are formed in pearlite and after isothermal treatment.

$Mn_{23}C_6$ and Mn_7C_3 equilibria with $(Fe,Mn)_3C$ are not established, except that the former two occur

Table IV

TERNARY CARBIDE SYSTEMS INVOLVING IRON AND CARBON*

System	Binary Compounds	Ternary Carbides	Solubilities of Carbides
Fe–Ni–C	Fe_3C, (Ni_3C)	None	Ni_3C and Co_3C intersoluble with Fe_3C, but unstable. Ni, Co in primary solution
Fe–Co–C	Fe_3C, (Co_3C)	None	Graphite equilibria
Fe–Mn–C	ε-phase (Fe–Mn binary, transient compound, hexagonal), Fe_3C, α-, β-Mn_3C, $Mn_{23}C_6$, Mn_7C_3	Probably a Mn-rich one	$(Fe,Mn)_3C$ continuous sol. sol. β-Mn_3C–γ-Fe intersoluble
Fe–Cr–C	FeCr (σ-phase), Fe_3C, $Cr_{23}C_6$, Cr_7C_3, Cr_3C_2	None	$(Fe,Cr)_3C$ up to 15% Cr (approx.) $(Cr,Fe)_{23}C_6$ up to 30% Fe ,, $(Cr,Fe)_7C_3$ up to 60% Fe ,,
Fe–V–C	FeV, Fe_3C, V_4C_3(VC), possibly V_2C	None	Carbides virtually insoluble
Fe–Ti–C	Fe_3Ti, Fe_3C, TiC	None	Carbides insoluble
Fe–Mo–C	FeMo (at high temps.), Fe_3Mo_2, Fe_3C, Mo_2C, MoC	Fe_4Mo_2C/Fe_3Mo_3C, $(Fe,Mo)_{23}C_6$	Fe_3C dissolves less than 0·5% of Mo Small Fe substitution in Mo carbides
Fe–Nb–C	Fe_3Nb_2, Fe_xNb_y (≃ $FeNb_2$), Fe_3C,-NbC(Nb_4C_3)	None	Carbides insoluble
Fe–Zr–C	Fe_2Zr_2, Fe_3C, ZrC	None	Carbides insoluble
Fe–W–C	Fe_3W_2, Fe_2W, Fe_3C, W_2C, WC	Fe_4W_2C/Fe_3W_3C, $(Fe,W)_{23}C_6$	Small Fe ⟷ W substitution in all carbides
Fe–Ta–C	FeTa, Fe_3C, TaC, Ta_2C	Probably none, but possible	Carbides insoluble

* Iron percarbide Fe_2C is omitted, as its ternary equilibria are not known (except in Jack's Fe–C–N system)

for alloys with more than 50% (approximately) of manganese (Öhman[81]). Schenck, Meyer, and Mayer[82] carburized iron–manganese alloys and suggested five undefined carbides (μ, μ_a, μ'_a, μ'_b, μ') besides (Fe, Mn)$_3$C; phase-fields described by these authors do not correlate with those given previously.

Öhman[81] reported a high-manganese double carbide, hitherto unconfirmed, occurring in an alloy with 68% of manganese, 25% of iron, 7% of carbon. (The approximate atomic formula works out as $Fe_{19}Mn_{56}C_{25}$, or (Fe,Mn)$_3$C with Mn : Fe = 3 : 1, but this is probably not the actual carbide composition.) The symmetry is monoclinic, with $a = 5{\cdot}05$, $b = 4{\cdot}56$, $c = 11{\cdot}61$ kX, $\beta = 97{\cdot}63°$, space group C_{2h}^6. Further details are unknown, and it is premature to speculate on its nature, considering the multiplicity of phases in the manganese corner, namely (*a*) metallic manganese with its three allotropic forms of anomalous structures, each possessing a different carbon solubility, (*b*) the β form of Mn_3C reported by Vogel and Döring (*cf.* Fig. 1 (*e*)), which, unlike α-Mn_3C, possesses a high solubility for manganese, and (*c*) the existence of Mn_7C_3 and $Mn_{23}C_6$ as alternatives to Mn_3C. Öhman's monoclinic carbide quite possibly corresponds to an intermediate form during transformations between iron solid solutions in any of these phases, and during the transition (Fe,Mn)$_3$C $\longleftrightarrow$ (Mn,Fe)$_7$C$_3$ + (Mn,Fe)$_{23}$C$_6$ it may well mark the junction in the ternary diagram between carbide class 3 (orthorhombic) and classes 1 and 2 (cubic and hexagonal). The possibility of an analogue of it existing in the iron–chromium–carbon system cannot be ignored.

Iron–Vanadium–Carbon

Phase-Fields : α, α + V_4C_3, α + V_4C_3 + Fe_3C, α + Fe_3C.

A diagram has been derived by Vogel and Martin[83] and by Wever, Rose, and Eggerts,[38] who give a space model. It has been reviewed by Desch.[37] A 4-phase reaction $\gamma \rightarrow \alpha + V_4C_3 + Fe_3C$ takes place at 690° C. The two carbides do not form solutions. The compound FeV probably coexists with α + V_4C_3, but this was not determined. Maurer, Döring, and Pulewka[35] discuss whether V_4C_3 *and* VC exist in steel. No attempt has been made to incorporate VC (or a possible V_2C) into the diagram.

Iron–Titanium–Carbon

Phase-Fields : α, α + Fe_3Ti, α + Fe_3Ti + TiC, α + TiC, α + TiC + Fe_3C, α + Fe_3C.

A diagram has been derived by Tofaute and Büttinghaus.[84] A critical review of published systems has been given by Northcott.[85] The section α-Fe $\rightarrow$ TiC is a pseudo-binary system, not $Fe_3Ti \rightarrow Fe_3C$ as suggested by Vogel[86]; Fishel and Robertson[87] studied the distribution of carbon between iron and titanium carbides. (*Cf.* also earlier remarks on TiC.)

Iron–Niobium–Carbon

Phase-Fields : α, α + Fe_3Nb_2, α + Nb_4C_3 + Fe_3Nb_2, α + Nb_4C_3, α + Fe_3C + Nb_4C_3, α + Fe_3C, Fe_3C + Nb_4C_3, Fe_3Nb_2 + Nb_4C_3.

A diagram has been derived by Eggers and Peter,[49] who also determined the binary system iron–niobium. A space model of the system is given. Decomposition $\gamma \rightarrow \alpha + Nb_4C_3 + Fe_3C$ takes place at 705° C. In their view, the carbide NbC is superseded by Nb_4C_3.

Iron–Zirconium–Carbon

Phase-Fields : α, α + Fe_2Zr_2, α + ZrC + Fe_2Zr_2, α + ZrC, α + ZrC + Fe_3C, α + Fe_3C, Fe_3C + ZrC, Fe_2Zr_2 + ZrC.

A diagram has been derived by Vogel and Löhberg.[88] The section α-Fe $\rightarrow$ ZrC is a pseudo-binary system, which divides the system into two distinct regions. Decomposition $\gamma \rightarrow \alpha$ + ZrC + Fe_3C takes place at 780° C.

Iron–Tantalum–Carbon

No information seems to have been published, but it is probable that the system will differ in important respects from the iron–niobium–carbon system, since two carbides, TaC and Ta_2C, exist. The existence of a ternary iron–tantalum–carbide (by analogy to the iron–tungsten–carbon) system is distinctly possible, though not reported.

The iron–chromium–carbon, iron–molybdenum–carbon, and iron–tungsten–carbon systems, omitted above, will be discussed in a later part.

Survey

One outstanding fact in surveying the systems (*cf.* Table IV) is the small number of genuine double carbides occurring. In most ternary systems the only carbides formed are solid solutions derived from the surrounding binary carbides; the chief ternary carbide established with an independent structure is Westgren's high-speed steel carbide Fe_4W_2C, with its isomorph Fe_4Mo_2C; here iron can be substituted up to the compositions Fe_3W_3C and Fe_3Mo_3C. The compounds (Fe,W)$_{23}$C$_6$ and (Fe,Mo)$_{23}$C$_6$ listed in Table IV are also true ternary carbides as far as the system iron–tungsten (molybdenum)–carbon is concerned, but are isomorphous with the binary $Cr_{23}C_6$. The approximate compositions of these compounds are $Fe_{21}W(Mo)_2C_6$. This is of obvious importance in discussing the quaternary system iron–tungsten–chromium–carbon.

Although it is possible that the existence of some ternary carbides in any of the systems has not yet been discovered, it appears that the consistent failure of previous investigators to detect any but the binary carbides in ternary alloys is not accidental; many of the equilibrium diagrams derived are sufficiently well founded to leave no room for the insertion of a ternary compound (*e.g.*, iron–nickel–carbon, iron–vanadium–carbon).

Among non-ferrous ternary carbide systems involving the present steel-alloying elements, Westgren and co-workers[54] have explored whether in the carbides Fe_3W_3C and Fe_3Mo_3C, iron is replaceable by chromium, manganese, cobalt, and nickel, with the result that the isomorphous carbides Co_3W_3C* and Ni_3W_3C exist; but these two can be decomposed by heat-treatment, the stability decreasing in the order $Fe_3W_3C \rightarrow Co_3W_3C \rightarrow Ni_3W_3C$. Molybdenum analogues of the same structure, such as "Co_3Mo_3C," have not been found, but Westgren observes "a pattern not agreeing with that of any known phase" in a 0·43% molybdenum, 0·87% carbon, cobalt–

* Westgren suggests the formula Co_4W_3C as more probably correct than Co_3W_3C.

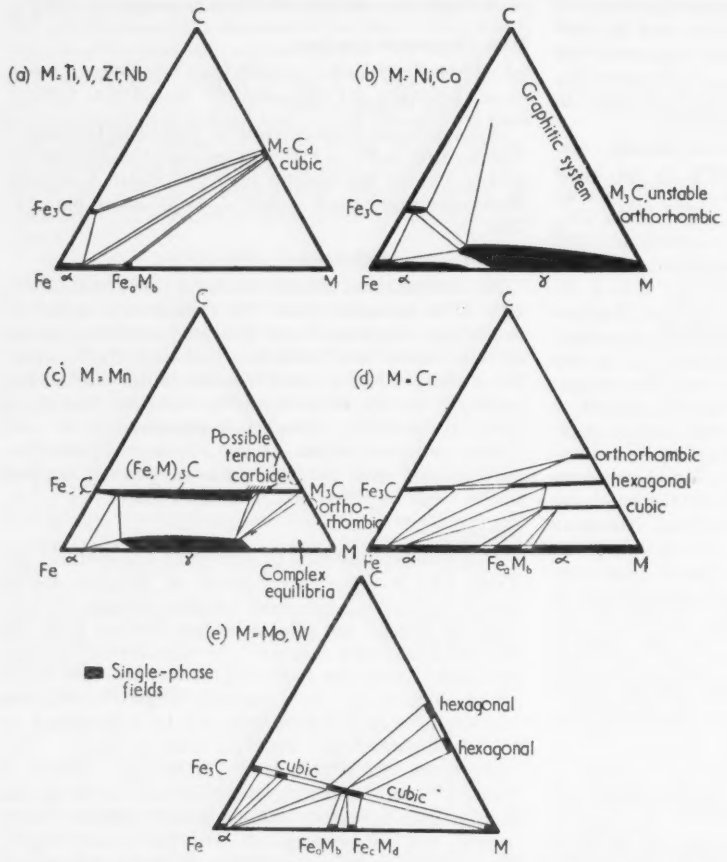


Fig. 8—Principal types of ternary carbide systems

molybdenum–carbon alloy. He also finds a " phase of unknown pattern " in the chromium–tungsten–carbon and in the manganese–tungsten–carbon systems, which may correspond to a double carbide of chromium–(manganese)–tungsten or a binary chromium–(manganese)–tungsten intermetallic compound. The lattice dimensions for the above three cubic compounds are given by Westgren as :

Fe_3W_3C 11·08 kX ; Co_3W_3C 11·01 kX ; Ni_3W_3C 11·15 kX

Among the present ternary systems five different types may be distinguished, represented diagrammatically in Fig. 8 (*cf.* also classes, p. 350). The types are directly related to the structure of the carbides and of the constituent metals :

Type (1)—*C.p. cubic carbide former* (*titanium, vanadium, zirconium, niobium, and possibly tantalum*) —Ferrite and the non-ferrous carbide form a pseudo-binary system. This divides the diagram into two fields, so that cementite cannot coexist with an intermetallic compound.

Type (2)—*Non-carbide former* (*nickel and cobalt*)— Ferrite, austenite, and cementite are the only stable phases (apart from graphite) and form a pseudo-ternary system.

Type (3)—*Orthorhombic* (*cementite-type*) *carbide former* (*manganese*)—A continuous series of solid solutions is formed between cementite and the non-ferrous carbide. In principle this is the same as type (2), since the α–γ–cementite pseudo-ternary system persists in the iron corner, modified only by the extension of the Fe_3C region. (This is consistent with the fact that if nickel and cobalt form their unstable carbides, these are also of Fe_3C structure.) A ternary carbide may occur under certain conditions, dependent on whether the solute remains a cementite-type of carbide former or simulates the transition type.

Type (4)—*Transition-type carbide former* (*chromium*)— Several non-ferrous carbides exist with a considerable solid solubility for iron. Equilibria occur as indicated in Fig. 8.

Type (5)—*Hexagonal carbide former* (*molybdenum and tungsten*)—Ternary carbides of cubic structure are formed in this type of diagram. Ferrite, cementite, and the non-ferrous metal itself form a pseudo-ternary system.

A detailed discussion of the connection between phase distribution and crystal structure must be left over to a separate account,* but one aspect is of special interest. Although types (1) and (2) represent opposite extremes in as far as in (1) the added metals are the strongest carbide formers (titanium, vanadium, zirconium, and niobium) and in (2) the weakest (nickel and cobalt), they nevertheless show an essential similarity if crystal structures are considered, as may be briefly shown in the following section.

Austenite and Carbide Structures

Petch[91] has shown that in austenite the carbon atoms occupy the octahedral positions of the face-centred cubic lattice, though, even for maximum saturation, only one among twelve of these sites is filled. Austenite may thus be regarded as isomorphous with the carbides of the NaCl type of structures, and structurally as a member of this group, but with most of the interstitial carbon positions vacated. The tendency for this defect lattice formation has already

* Reference should be made to a paper by Shapiro and Strauss,[89] which deals with the position of the eutectoid in the iron–carbon system, as influenced by various elements, surveys the literature, and classifies the data. A valuable review on carbides has recently been carried out by Banyard.[90]

begun amongst the cubic carbides, when arranged according to the periodic table :

$$TiC \longrightarrow V_4C_3 \longrightarrow Cr_{23}C_6, Mn_{23}C_6 \longrightarrow \text{austenite } [(Mn,Fe,Co,Ni)_nC]$$

(*Cf.* earlier discussion on p. 350 and also Fig. 2)

The character of austenite as "a carbide" of the cubic (class 1) type, in which no more than 12 carbon positions are occupied, is reflected in the ternary diagrams of types (1) and (2) above. They do not differ in principle, but only in so far as the Fe_3C + (*e.g.*) TiC duplex region in (1) is replaced by the Fe_3C + austenite region in (2), with a consequent shift of phase-fields into the iron corner.

In practice, the implication is that austenite and the cubic carbides should show a tendency to form, at high temperatures, continuous or large series of solid solutions, provided that atomic sizes permit. This agrees with actual observation, *e.g.*, in heat-resisting steels at high temperatures; the example of the titanium-bearing steel mentioned earlier (p. 352) is also a case in point. The mechanism of precipitation of the cubic carbide from austenite is then essentially one of carbon atoms segregating in certain lattice regions of the parent crystal, causing an expansion and eventual division into two related phases.

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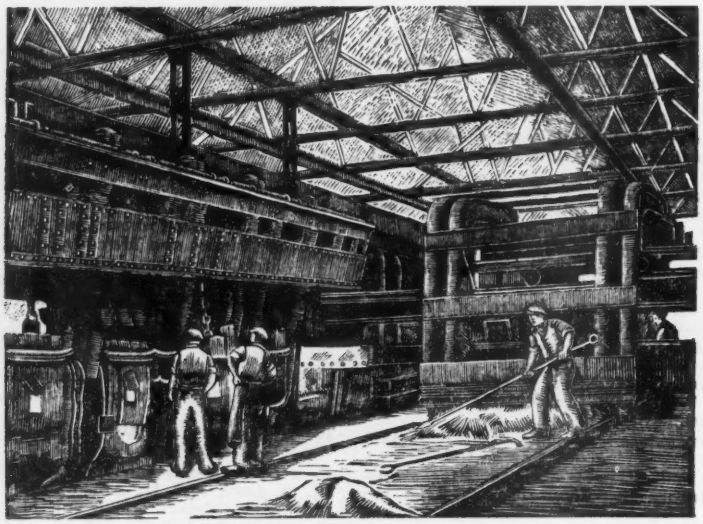

Charging Steel Scrap into a Steel Furnace,
from an original woodcut by Viva Talbot

The Wire-Drawers' Craft

AS PRACTISED IN THE WARRINGTON DISTRICT

By G. K. Rylands, O.B.E., and A. E. Sykes

THE process of wire-drawing is one of great antiquity and considerable skill is involved in drawing sections of all types. The tungsten-carbide die is rapidly replacing the old methods of wire-drawing and in the course of time it will undoubtedly be applied elsewhere in the trade, although sections other than round are still drawn mostly through plates. In perhaps another generation the old wire-drawer will be extinct, and yet another ancient craft will have been replaced by modern methods. It may be of interest therefore, from the historical point of view, to describe the process as practised at Messrs. Rylands Brothers, Ltd.

The old type of wire-drawer's plate is made of high-carbon steel containing a number of holes to suit the size of wire for which the plate is designed. It is about $1\frac{3}{8}$–$1\frac{3}{4}$ in thick with a shank at one end. The holes are first hot pricked to a taper and the back of each hole is then drilled out parallel to within about half-an-inch of the face of the plate. The diagram below shows a typical wire-drawer's plate and the standard specification for hot pricking.

The wire-drawer's first necessity is to provide himself with a suitable punch. In the old days he made this in his kitchen or in a shed in his yard, using a small grindstone which was generally turned by one of the members of the family or by his mate from the works. When the punch was ground to his liking it was heat-treated in the kitchen fire by inserting the punch into a tube with a closed end and placing the tube through the fire bars; the necessary heat was obtained by the use of bellows or a suitable blower.

Since the grindstone was small it was impossible for anything but a concave punch to be ground on it, and indeed, in the early days, the use of a concave

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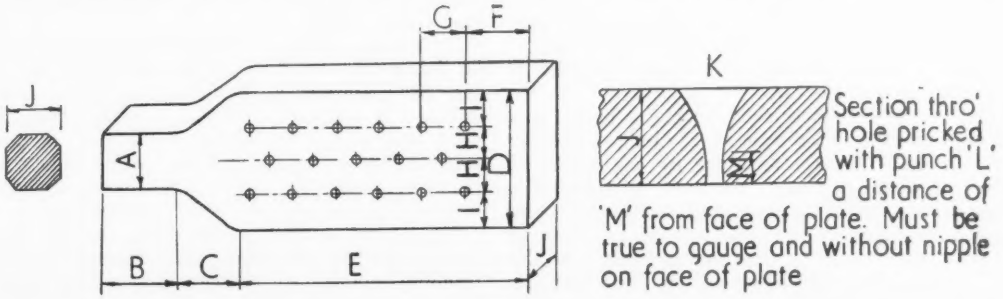
Mr. Rylands is General Manager and Director, and Mr. Sykes is a Wire Department Manager of Messrs. Rylands Brothers, Ltd., Warrington.



Gauge	1/0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	2"	2"	2"	2"	2"	2"	2"	2"	2"	1 3/4"	1 3/4"	1 3/4"	1 3/4"	1 3/4"	1 3/4"	1 3/4"	1 3/4"	1 3/4"	1 3/4"
B	3"	3"	3"	3"	3"	3"	3"	3"	3"	3"	3"	3"	3"	3"	3"	3"	3"	3"	3"
C	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	2"	1"	1"	1"
D	5 1/2"	5 1/2"	5 1/2"	5 1/4"	5 1/4"	5 1/4"	5"	5"	5"	4 3/4"	4 3/4"	4 3/4"	4 3/4"	4 3/4"	4 1/2"	4 1/2"	4"	4"	4"
E	11"	11"	11"	11"	11"	11"	11"	11"	11"	10"	10"	10"	9 1/2"	9 1/2"	9"	9"	8 1/2"	8 1/2"	8 1/2"
F	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2 1/2"	2"	2"	2"
G	2"	2"	2"	1 11/16"	1 11/16"	1 11/16"	1 1/2"	1 1/2"	1 1/2"	1 1/4"	1 1/4"	1 1/4"	1 3/16"	1 3/16"	1 1/8"	1 1/8"	1"	1"	1"
H	1"	1"	1"	1 1/8"	1 1/8"	1 1/8"	1"	1"	1"	1"	1"	1"	1"	1"	1"	1"	1"	1"	1"
I	1 3/4"	1 3/4"	1 3/4"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 3/8"	1 3/8"	1 3/8"	1 3/8"	1 3/8"	1 1/4"	1 1/4"	1"	1"	1"
J	1 3/4"	1 3/4"	1 3/4"	1 3/4"	1 5/8"	1 5/8"	1 5/8"	1 5/8"	1 5/8"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 3/8"	1 3/8"	1 3/8"	1 3/8"
K	1 1/8"	1 1/8"	1 1/8"	1"	1"	1"	7/8"	7/8"	7/8"	7/8"	3/4"	3/4"	3/4"	3/4"	3/4"	5/8"	5/8"	5/8"	5/8"
L	13°	13°	13°	13°	13°	13°	13°	13°	13°	8.5°	8.5°	8.5°	8.5°	8.5°	8.5°	8.5°	8.5°	8.5°	8.5°
M	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"	7/16"	7/16"	7/16"	7/16"	7/16"	7/16"
No. of holes	12	12	12	15	15	15	18	18	18	18	18	18	18	18	18	18	18	18	18

or hollow-ground punch was essential. Apprentices were always told to grind their punches to the same shape as the Blackpool Tower. In grinding the punch the wire-drawer worked to the picture in his mind's eye of the type required for the job. When ground he checked the length of bearing by finding, with a nick gauge, the positions on the punch at which its diameter was equal to the wire before and after drawing. To do this satisfactorily a very high degree of skill was necessary; the section had to be kept perfectly round, and the general taper, which the wire-drawer knows to be necessary, had to be maintained. On the small grindstone, too, the job was exceedingly laborious.

In setting the hole, the wire-drawer placed one end of the plate on the bench and rested the shank on his leg above the knee. He then drove the punch into the hole and judged from the feel of the end protruding through the face of the plate whether he had driven it far enough. The size of the hole was then gauged by a setting-stick which was merely a round wire of the correct size with a pointed end.

The concave or hollow-ground punch made a tapered hole with a virtual parallel. Here again, much skill was required in punching out of the hole the correct amount and obtaining a solid well-shaped bearing, for with the use of the setting-stick there was no certainty of obtaining a size with a sufficient degree of accuracy. In about 1906 the "set" was introduced which was virtually a round wire of the size required and which was driven through the hole after it had been punched out to a somewhat lesser diameter. This had the effect of making a definite parallel in the exit portion of the hole.

For very light reductions a straighter punch was necessary and the wire-drawer always judged whether or not a punch was satisfactory by the length of bearing it would produce. The angle of taper of a hollow-ground punch varies throughout its length, and a skilled wire-drawer could usually produce a universal punch to operate more or less satisfactorily over the range of wire sizes he was producing. For example, in the first hole from the rod, the upper portion of the punch would form the bearing where the angle was relatively steep. In the next hole, where the finished wire was finer, the bearing would be formed by a length of the punch nearer the point, where the angle would not be so steep.

The use of the hollow-ground punch gradually declined with the introduction, in about 1917, of the machine-ground punch. In this case straight conical punches of different angles were produced, the angles depending upon the job. However, there was a distinctly limited range in which a punch could be used effectively. If the angle was too steep, even the most powerful wire-drawer could not punch out the hole and obtain a sound bearing. On the other hand, at a certain minimum angle the punch would jam in the hole, and the limit at which this occurred was still too steep to obtain satisfactorily the minimum reductions of area which might sometimes be required.

Setting with a straight-tapered punch was certainly easier than with a hollow-ground punch, and a greater degree of accuracy was possible in the diameter of the wire drawn. The process, however, was much the same. When the wire-drawer was of the opinion that he had punched the hole far enough, he drove his set through it, thereby opening out the last portion of the tapered hole and leaving the parallel extension to the bearing. By this method there was no offset such as is obtained in grinding out a tungsten-carbide die, and the length of the parallel part of the hole depended on how far the hole had been punched out before driving the set. By skilful adjustment it was usually possible to adjust the length of parallel so that it was approximately equal to half the diameter of the wire.

After setting, there was generally a slight burr left at the face of the plate, and this was carefully removed with a chisel worked outwards from the centre of the hole. In some cases, after the burr had been removed, a slight countersink was applied by means of a rounder.

The preparation of punches after working hours was a laborious and tedious job, and though many wire-drawers provided themselves with a useful range of tools for a variety of jobs, there were others who liked to have one good punch which they could use for any round-wire job they were likely to carry out. Although many of the old wire-drawers were reluctant to adopt the machine-ground punch, the advantage of its use soon became apparent, as a single punch with a 10° included angle would cover a very wide range of jobs. Before the introduction of the machine-ground punch it was a disaster if a man broke a punch, for if he had no spare available he might easily lose a day's work.

As already stated, a straighter punch is necessary for lighter jobs, but if a suitable punch is not available the wire-drawer uses one with a full taper, and the difficulty is overcome by a trick, which, although not good practice, is frequently successful. If a very straight hole is required, the hole, when punched out, is left very tight for the set, and driving a tight set virtually produces a hole with a straight taper.

Having set the hole in the plate, the wire-drawer proceeds to draw wire through it. Finishing holes will probably not last more than one or two pieces of 1½ cwt each. Roughing holes, however, will last longer and a good man may get as many as ten pieces through one setting. When the finishing hole has a tendency to mark, or is running full to gauge, it is necessary to reset, and the plate is knocked up cold by striking blows with a hammer round the hole, but never on the hole. The hole is then repunched and reset.

This process is repeated until all the wire roughed through one hole has been drawn through the finishing hole, whereupon this finishing hole is abandoned and the wire-drawer moves on to the next one in the plate. When all the holes have been worked out the plate is subjected to hot battering. In this process the plates are heated to a red heat and a pneumatic hammer is worked round the holes to close them. Pneumatic hammers were introduced about 1916, but before then hot battering was done by hand on an anvil formed from a coil of defective rod, as this was found to be far better for the purpose than the ordinary blacksmith's anvil. After hot battering the plates are allowed to cool out, and are then returned to the mills for further use.

A Method of Identifying Manganese-Sulphide Inclusions in Steel

By J. H. Whiteley, D.Sc., F.R.I.C.

SYNOPSIS

A method is described of identifying manganese-sulphide inclusions by means of Selvyt cloth which has been soaked in a solution of silver nitrate and well washed.

INCLUSIONS of manganese sulphide are, as a rule, not difficult to identify, but occasionally some uncertainty may arise, especially when the steel is low in sulphur and high in ferrous-oxide content. Inclusions of that compound are often very similar in colour to those of MnS, although somewhat darker, and, unless the two occur together or in juxtaposition, it is quite possible for one to be mistaken for the other. One way to distinguish between them is to immerse the specimen for a few minutes in a very weak acid, such as a 2% solution of hydrochloric acid in alcohol. In such solutions FeO is more readily soluble than MnS and can thus be completely or partially removed while the MnS remains intact. The disadvantage of the method is that for further examination of the oxide a fresh surface is required. With the following method that drawback is obviated, since neither type of inclusion is attacked ; in fact, the same inclusions can be tested repeatedly simply by repolishing the surface.

In applying the method the specimen is first prepared by wet polishing with any suitable powder on a revolving table covered either with Melton broadcloth or Selvyt. The author uses powder obtained by elutriating alumina listed in the dealer's catalogue as "levigated," and this is treated as follows : From 100 to 150 g. are well stirred with about 550 c.c. of water in a 600-c.c. beaker. After standing for 2 min. a decantation is made, and the alumina which remains in suspension is allowed to settle, after which it is collected and dried. Very little of this material is needed on the cloth to obtain a satisfactory polish for general purposes. The finish may be still further improved by polishing on a wet strip (about 4 in. × 1½ in.) of rayon locknit with from 0·005 to 0·01 g. of alumina, prepared by calcining aluminium sulphate for 1 hr. at 1000–1100° C. The strip is held down with one hand on a glass plate and the specimen rubbed fairly rapidly, with medium pressure, for about 1 min., which usually suffices to produce an excellent degree of polish.

All that is now required for the test is a similar strip of unused Selvyt cloth which has been soaked for a few minutes in a recently made solution of silver nitrate, say, 5%, and then thoroughly washed under the tap so as to remove all the unadsorbed silver. The wet strip is placed, nap side up, on a glass plate, and the prepared surface is gently rubbed on it. The amount of rubbing needed must be found by trial, but generally, from 100 to 150 strokes in one direction will serve, or else a quick to-and-fro motion for about 15 sec. The result is that some of the adsorbed silver is transferred from the cloth to the MnS (or FeS) inclusions, so that under a good vertical illumination they can look as white as, or even whiter than, ferrite. Should they be dull or have a dark mottled appearance, as sometimes happens, rubbing for 10 or 15 sec. on the locknit silk will brighten them. The precise nature of the film thus produced has not been ascertained ; most likely it is reduced silver, since oxide inclusions of all types remain unaffected. Depending upon their size, quite a number of specimens can be used on one strip of Selvyt, but eventually a stage will be reached at which the MnS inclusions are not completely coated, owing to the gradual depletion of the adsorbed silver. They have then a streaky appearance such as that seen in two of the inclusions in Fig. 13.

If the impregnated cloth is not used at once, its effectiveness will remain unimpaired for 2 or 3 days, though not much longer. Several other materials have been tried for holding the silver, including artificial silk, lint, and filter paper, but Selvyt has been the most satisfactory. Lint and cotton wool failed to act even when unwashed after a long soak in the silver solution ; at best only traces of the white film on the MnS inclusions would be obtained with them.

To illustrate the change in the appearance of the sulphide inclusions on applying the test, several examples have been selected and a description of them follows.

Figure 1 shows four MnS inclusions, three of which are bordered with a film of silicate. They occurred in the high-sulphur free-cutting steel ingot described by Gregory and Whiteley.* The same inclusions are again seen in Fig. 2 after the surface had been rubbed on the silverized Selvyt cloth.

Figures 3 and 4 show two composite inclusions of a glassy silicate and MnS in a nickel–chromium–molybdenum steel, before and after the treatment, respectively.

Figure 5 shows inclusions of iron-oxide/sulphide eutectic which were obtained in the following way : A hole was drilled in a small block of steel, 1 in. sq. section, containing C 0·25%, S 0·04%, and Mn 1·55%. Into the hole was inserted a loosely fitting

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Dr. Whiteley is at the Consett Iron Co., Ltd.

* E. Gregory and J. H. Whiteley, *Journal of The Iron and Steel Institute*, 1941, No. II, pp. 9P–32P.

plug of the same steel, thinly coated with a paste consisting of a mixture of FeO and FeS, both prepared from electrolytic iron. When the paste had dried the cavity was sealed by arc welding, and the block was forged, at about 1100° C., into a $\frac{3}{8}$-in. sq. bar. On examining a section, FeO and the FeO/FeS eutectic appeared in quantity at the weld junction and, in order to convert the FeS partly to MnS, the specimen was heated in a closed silica tube for several hours at 1050° C., after which the tube was air-cooled. The eutectic was then seen to consist of FeO, MnS, and a little FeS, and it is this complex which is shown in Fig. 5. As is usual when associated with FeS, the MnS was rather light in colour. The same area after the new method had been applied is shown again in Fig. 6, from which it is evident that the MnS and FeS were equally whitened.

Figure 7 shows an MnS inclusion and some darker FeO inclusions observed in a billet containing 0·20% of C, rolled from the top end of a 3-ton ingot, the pipe of which had become lined with iron oxide in the soaking pit. The same area after rubbing the surface on the Selvyt is seen in Fig. 8, and it will be noticed that only the MnS inclusion has whitened. In order to demonstrate that the other inclusions were chiefly FeO, the specimen was immersed for 3 min. in a 2% solution of hydrochloric acid in alcohol. The result is shown in Fig. 9. Dark cavities were present where the FeO had been, while the MnS had remained unattacked.

Many samples of steel have been examined by this method and, so far, only two have been found in which the test seemed to fail. Both cases were free-cutting steels, and in each there were some inclusions, which were apparently MnS associated with silicate, that would not whiten. One of these samples was that of the previously mentioned high-sulphur steel ingot. In this, as in the other one, were globules of striking appearance, consisting of a silicate in which were embedded particles of MnS, FeO, and chromite (*see* Fig. 10). Presumably all the dove-coloured beads to be seen there were MnS—in any case that was indicated by the solubility test—and yet only the particles near to, and at, the periphery would take the silver, as Fig. 11 will show. All attempts, including shorter and much longer rubbing on the Selvyt, failed to induce the interior beads to whiten. Moreover this peculiarity was not confined to the large silicate globules ; the MnS, if such it is, acted in the same way in some of the smaller ones. Instances are shown in Figs. 12 to 15. Obviously the failure was not due to the size of the silicate globule ; that was also evident when a specimen from a forged portion of the ingot was examined, for although the large silicate globules had been elongated and broken up, some of the dove-coloured beads in them still would not respond to the treatment, as is shown in Fig. 16. If these beads are chiefly MnS, which is most likely, this behaviour suggests that their composition is somewhat different from those at the margins.

Correspondence on the Paper—

APPLICATION OF SLAG CONTROL AND INVESTIGATION OF BASIC OPEN-HEARTH-FURNACE-SLAGS* *by T. Fairley*

Mr. **C. de Klerk** (Nederlandsche Kabelfabriek, Alblasserdam, Holland) wrote : With reference to the paper by T. Fairley, an investigation was made at our laboratory about the correctness of the rapid method of determination of slags.

Several samples have been investigated by the general long method† in use at our laboratory, and by the rapid method as mentioned in Dr. Fairley's paper. With the latter method, however, we found too high a value of calcium oxide. In comparison with the long method, the difference between these two methods amounts to 2–3% in our slags. In order to investigate the cause of this, we have proceeded to make an artificial slag. For this purpose the quantities of the elements were taken in conformity with the quantities of a final slag (as taken by making the manganese proof).

The following successive investigations were made :

(1) Determination of CaO in a solution of a known quantity of $CaCO_3$.

(2) Determination of CaO in a solution of known quantities of $CaCO_3$; $MnCl_2$; $MgCl_2$; $FeCl_3$; and H_3PO_4.

In (1) we found 55·33% of CaO average, and in (2) 58·46% of CaO. The value of the second determination therefore is considerably higher.

Determination in a solution of known quantities :

	CaO, Av., %
$CaCO_3 + MnCl_2 + MgCl_2 + H_3PO_4$ ...	58·43
$CaCO_3 + MgCl_2 + H_3PO_4 + FeCl_3$ ...	55·31
$CaCO_3 + MnCl_2 + H_3PO_4 + FeCl_3$ ...	58·39
$CaCO_3 + MnCl_2 + MgCl_2 + FeCl_3$ ...	58·30

We saw that by the elimination of manganese we arrived at the original value of CaO in $CaCO_3$; average 55·31% of CaO. The presence of manganese must be the reason why the amount of CaO is too high with the rapid method. Further investigations point to the fact that manganese also precipitates in the shape of an oxalate, as does calcium, when ammonium oxalate is added.

We should be very pleased to hear if there are other ways of carrying out the rapid method without the presence of manganese causing trouble.

AUTHOR'S REPLY

Dr. **T. Fairley** (The Park Gate Iron and Steel Co., Ltd.) wrote in reply : We have found that the quick method of analysis for lime in basic open-hearth slags, described in my paper, sometimes gives high results, and we agree that the error may be as much as 2·0%. It should be appreciated, however, that the lime-content value is not used in the slag-control calculations which are explained in the paper. Hence, the amounts of lime and oxides charged into the furnace are not affected by any error in the value obtained for the lime content.

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* *Journal of The Iron and Steel Institute*, 1947, vol. 155, February, pp. 161–171.

Contribution received 18th June, 1948.

† *Handbuch für das Eisenhütten-Laboratorium*, vol. I, p. 148.

Fig. 1—MnS inclusions in 0·45% S free-cutting steel ingot × 330

Fig. 2—Same area as Fig. 1. After test × 330

Fig. 3—MnS associated with silicate in Ni-Cr-Mo steel × 520

Fig. 4—Same area as Fig. 3. After test × 520

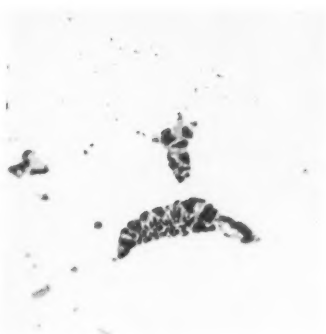


Fig. 5 — MnS/FeS/FeO eutectic × 760

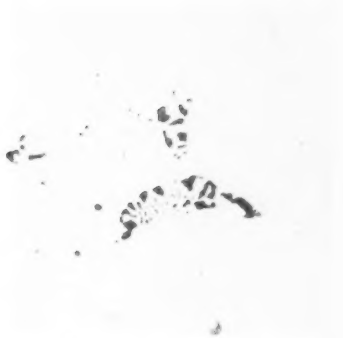


Fig. 6—Same area as Fig. 5. After test × 760

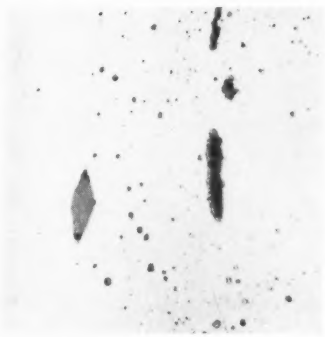


Fig. 7—MnS and FeO inclusions in steel billet × 520

Fig. 8—Same area as Fig. 7. After test × 520

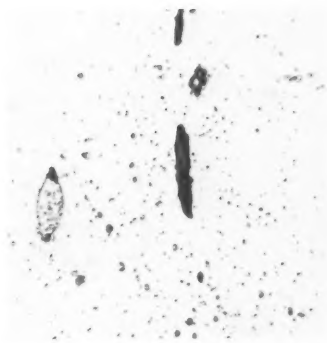


Fig. 9—Same area as Fig. 7 and 8. After 2% HCl test × 520

Fig. 10—Silicate globule with MnS and chromite in 0·45% S steel ingot × 330

Fig. 11—Same globule as in Fig. 10. After test × 330

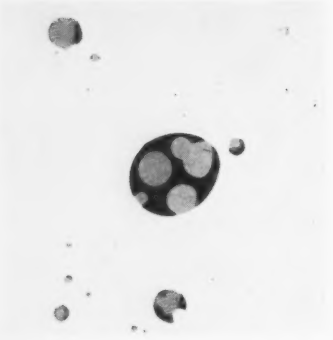


Fig. 12—Silicate globules with MnS in 0·45% S steel ingot × 330

Fig. 13—Same area as in Fig. 12. After test × 330

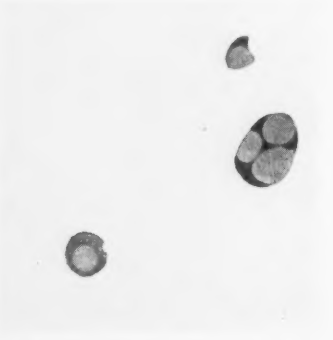


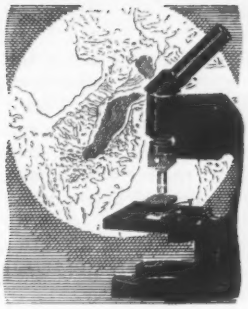
Fig. 14—Silicate globules with MnS in 0·45% S steel ingot × 330

Fig. 15—Same area as Fig. 14. After test × 330

Fig. 16—Silicate with MnS in forged 0·45% S steel. After test × 330

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



A Study of the Corrosion Resistance of High-Alloy Steels to an Industrial Atmosphere

By H. T. Shirley, B.Sc., A.R.C.S. and J. E. Truman, A.Met.

SYNOPSIS

The tests described were designed to study the effects of composition and surface finish on the behaviour of higher alloy steels when exposed for prolonged periods to severely industrial atmospheric conditions, without attention to the cleansing treatment normally recommended for such materials. The intention was twofold ; the results to provide information as to the most suitable compositions for use where regular cleansing would be impracticable, and also to serve in comparing, directly, the behaviour of these higher alloy steels with that of lower alloy steels exposed under similar conditions.

The series included some 450 samples, covering 22 steels and 5 non-ferrous materials, all in sheet form. The three types of surface finish tested were pickled, emeried, and mirror-polished. Exposure was for 2 and 5 years with vertical specimens, and for 5 years with specimens exposed at 12° to the horizontal.

In respect of composition, the behaviour of 18/8/2½ chromium–nickel–molybdenum and 24/12/3 chromium–nickel–tungsten steels was outstandingly good, with losses of the order of only one thousandth that of mild steel. In general the more resistant steels tended to show higher losses in the case of the emeried samples, than for the other two surface finishes, the effect being small for the vertical exposure stands, but more considerable in the case of the horizontal stands. Although comparison with earlier tests for 1 month indicated a general tendency for higher rates of loss in the initial stages of exposure, there was no indication of any notable change in rate of attack with time over the 2-year to 5-year periods. The losses were considerably higher than various reported figures from American tests (reflecting the greater severity of the test conditions), and were much less favourable to plain 18/8 chromium–nickel steel than reports, based on exposure, by some other investigators.

The results for the non-ferrous materials were in line with those expected from previously published figures, and show all five materials to give higher losses than most of the special steels. Although, in some cases, this may be offset to some extent by a pitting tendency in the case of the steels, the outstanding superiority of the 18/8/2½ chromium–nickel–molybdenum and 24/12/3 chromium–nickel–tungsten steels is clearly demonstrated, with losses of the order of only a hundredth of those of the non-ferrous materials.

Introduction

THE development of the corrosion-resisting higher alloy steels has been very closely associated with chemical engineering projects. Interest has therefore been focused to a great extent on their resistance to a variety of special media, often of considerable corrosivity. In such circumstances a satisfactory resistance to atmospheric corrosion is usually a secondary consideration and taken for granted, no precise study of relative resistance to this form of attack being required. On the other hand, in structural engineering, where resistance to atmospheric corrosion is often of major interest, considerations of cost and supply rule out the use of such materials for most ordinary structural work, and normally limit it to the decorative aspect. Here, regular cleansing is essential to remove deposited dirt if the material is to be used to proper advantage, and in such circumstances most of the more resistant materials suffer virtually no attack. Thus, once again, relative resistance to atmospheric corrosion is of secondary importance, overruled in this case by such considerations as ease of fabrication and cost.

From time to time, however, cases have arisen where regular cleansing of these materials, under conditions of decorative or structural application, has been impossible or impracticable, and in such cases the relative resistance of the various steels becomes a matter of more direct interest and importance. Even in these circumstances the plain 18/8 chromium–nickel type of steel may prove satisfactory. For

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Mr. Shirley is Chief Chemist and Mr. Truman a member of the staff at the Brown-Firth Research Laboratories.

example, very favourable reports have been made in regard to its behaviour in the case of certain high buildings in New York.[1] On the other hand, where highly polluted atmospheres have to be faced, such material would not, generally, be fully resistant, and local rusting with pitting would occur in the absence of proper cleansing treatment. Even where cleansing is carried out, severity of conditions, or relative infrequency of attention, may make it desirable to consider alternative compositions which have a greater margin of safety.

Considerations such as this, coupled with a desire to provide a more complete picture of the effect of alloy additions by extending the tests on low-alloy steels to these higher alloys, led, in 1938, to the planning of the series of tests which form the subject of the present paper. It was originally intended that they should be carried out in parallel with an extensive programme of tests on lower alloy steels then under discussion by the Corrosion Committee,* specimens for which would be tested on stands adjacent to the present series.[2] Unfortunately, for reasons arising mainly from wartime conditions, it did not prove possible to expose the lower alloy series until 1946, so that completion of the five-year tests will be delayed until 1951. The present series was exposed in September 1938 and completed in 1943, and in view of a growing interest in the relative behaviour of the higher alloy steels it has been considered desirable to publish the results of this series without further delay.

PREVIOUS INVESTIGATIONS

Before describing the present tests it will be useful to note, briefly, some relevant investigations from previous publications.

In a paper included in the Second Report of the Corrosion Committee,[3] W. H. Hatfield and one of the present authors described atmospheric tests carried out for periods of a month and a year in the same location as the present tests. The samples were exposed on horizontal frames similar to those used in the present series, and included a number of higher alloy chromium–nickel steels. The results, in general, agree with those of the present 5-year tests, and will be considered further in the general discussion of results later in the paper.

Mention has already been made of the American Society for Testing Materials' reports on the behaviour of 18/8 chromium–nickel steel on various buildings.[1] In addition, several other American papers are of particular interest.

I. V. Williams and K. G. Compton[4] describe tests involving exposure for 15 years to New York City atmosphere. They found that 13% chromium steel showed considerable surface rusting, but that 18/8 chromium–nickel steel and 17% chromium steels rusted only slightly, with losses of the order of 0·002 and 0·001 g./sq. in. respectively, throughout the whole period (equivalent to 0·00013 and 0·00007 g./sq. in./yr.).

W. O. Binder and C. M. Brown[5] give data on weight-loss, and appearance, for a series of steels with increasing chromium contents up to 18%, exposed for periods up to 52 months at Kure Beach, Niagara Falls, and New York. The total loss in four years for the 18% chromium steel was of the order of 0·001–0·003 g./sq. in. (0·0002–0·0007 g./sq. in./yr.) with practically no pitting. This compares with 0·005–0·01 g./sq. in. (0·001–0·002 g./sq. in./yr.) for 13% chromium steel and 0·3–0·6 g./sq. in. (0·07–0·15 g./sq. in./yr.) for mild steel. These authors also tested cold-rolled, austenitic chromium–nickel and chromium–manganese steels, but the quantitative study in this case was confined to the tensile properties, which after 5 years' exposure to an industrial atmosphere at Niagara Falls showed no loss of strength or ductility. In addition, they found that stress had no apparent effect on the corrosion of stressed specimens exposed to a marine atmosphere at Amogansett.

A. P. Jahn[6] reports the absence of any serious attack on 12% chromium or 18/8 chromium–nickel steel wires exposed for nine years at a variety of exposure sites. In general the 18/8 chromium–nickel wires retained their metallic lustre.

W. A. Wesley and H. R. Copson[7] are testing 18/8 chromium–nickel, 18/12/2 chromium–nickel–molybdenum, and 18/8/3 chromium–nickel–molybdenum steels in the form of wire-insect screens. The tests have been in progress for varying periods since 1932, exposed in sulphurous, marine, and rural atmospheres. Behaviour has been assessed by appearance and loss of strength. Plain 18/8 chromium–nickel steel was found to suffer rapid pitting in corrosive atmospheres, especially where sheltered. Much superior results were given by the molybdenum-bearing material, which the authors say will long outlast bronze.

W. Mutchler[8] in tests with thin sheets exposed for three years to marine atmospheres also reported much less rusting with 18/11/3½ chromium–nickel–molybdenum steel than with 18/9 chromium–nickel steels with stabilizing additions of titanium and columbium.

A particularly interesting series of chromium and chromium–nickel stainless steels has been described by G. L. Snair, Jr.[9] These tests covered chromium steels from 12 to 28%, and chromium–nickel steels from 18/8 to 24/16 types. Specimens were also included from 18/9 chromium–nickel stabilized with columbium, titanium, and vanadium, and of 19/9 chromium–nickel with 2½% molybdenum. The samples were in sheet form with varying surface finishes, and were tested for ten years in a severely industrial atmosphere. Assessment has been by inspection of appearance only, and the author groups the steels in order of resistance, putting the very slightly attacked molybdenum-bearing material first, followed by the 28% chromium steel. The third group contains most of the other chromium–nickel steels, and these are followed by the plain chromium steels in descending order of chromium content, the 12% chromium steel being covered with heavy rusting and fine pitting. Surface finish, from descaling to mirror polish was not considered to have had any important influence.

*The Joint Corrosion Committee of The Iron and Steel Institute and the Iron and Steel Federation, now taken over by B.I.S.R.A.

Finally, C. P. Larrabee[10] surveys data from various tests relating to marine atmospheres, and refers to a series at Kure Beach from which the following qualitative conclusions were drawn :

(1) The 12% chromium steel (Type 410) acquires a red rust over a part of its surface within a few months.

(2) The 17% chromium steel (Type 430) becomes " rusted " over a part of its surface after a year or so. The red rust on polished specimens can be removed by rubbing with a polishing compound such as powdered tripoli.

(3) The 18/8 chromium–nickel material (Type 304) soon becomes " stained " with a very superficial yellowish substance over a small part of the surface. In many cases this substance changes to a reddish colour after a few years, but it can be removed as mentioned above.

(4) The presence of 2% to 3% molybdenum (Type 316) greatly improves the resistance to attack, as it does also when the steel is immersed in sea water.

(5) The superficial " staining " is of less degree on the higher alloys, such as 25/12 chromium–nickel steel (Type 309) or 25/20 chromium–nickel steel (Type 310), than on 18/8 (Type 304), but even the 25/20 steel is not superior to the 18/8 molybdenum (Type 316).

In the discussion on the paper by Larrabee, W. O. Binder[11] stated that, " It is well known that steels containing approximately 12% chromium, with normal amounts of manganese and silicon, are free from progressive atmospheric rusting."

It will be noted that some American tests have given results very favourable to plain 18/8 chromium–nickel steels, although the A.S.T.M.[1] report recognizes the necessity of proper cleansing to avoid pitting in highly polluted atmospheres. Both maximum corrosion and differentiation between the various compositions will, of course, occur in such highly polluted atmospheres. The results of the present tests, which have been deliberately carried out without cleansing in a highly corrosive industrial atmosphere, are, therefore, not only much less favourable to the plain 18/8 chromium–nickel steel, but emphasize strongly the advantage of certain special alloy additions, particularly molybdenum.

METHODS OF TESTING

The series included about 450 samples, covering 22 steels and 5 non-ferrous materials. They were all taken from sheet material of 16–20 gauge, with one exception at 12 gauge. The steels were taken from works' stock and were all in a normally heat-treated condition. The non-ferrous materials were purchased through ordinary commercial channels, and were not further heat-treated. All materials were analysed, and details of composition, gauge, and heat-treatment will be found in Table IV. The samples were sheared to 4 in. × 4 in. and the edges emeried, polished, or pickled, according to the general finish of the samples. Holes with a diameter of $\frac{3}{16}$ in. were drilled at the corners for suspension.

Three types of surface finish were used : pickled, emeried, and mirror-polished. The emeried samples were finished with 120-grade cloth, while the mirror-polished samples were finished with 180-grade, followed by polishing on a mop dressed with a chromic-oxide grease composition. Pickling of the steels was according to commercial practice. The mild steel and low-alloy nickel–chromium–molybdenum steels were treated in 10% by volume of sulphuric acid at 50° C. The other steels were treated in either a sulphuric-hydrochloric acid bath or a hydrochloric-nitric acid bath, followed in both cases by final treatment for about 5 minutes at 35° C. in a bath containing 20% by volume of concentrated (70%) nitric acid, and 0·5% of concentrated (60%) hydrofluoric acid. The pickling of the non-ferrous materials was carried out by immersion at 50° C. in a bath containing 25% of concentrated hydrochloric acid and 5% of concentrated nitric acid, to give a chemically attacked surface with a loss in thickness of the order of 1 mil. This required only a few seconds in the case of materials *A*, *D*, and *E*, and about 10 minutes for *B* and *C*.

The samples were cleaned in alcohol, weighed, and exposed on vertical and horizontal wooden stands on the roof of the Brown-Firth Research Laboratories. The horizontal stands were of the type described by U.R. Evans,[12] the specimens being supported at an angle of about 12° to the horizontal by screwing down at one end on to wooden rails with a $\frac{3}{4}$ in. overlap, using 12/12 chromium–nickel stainless steel screws for fixing. The vertical frames had a series of rails, staggered to prevent any row of specimens directly overhanging lower rows. These rails carried suspension hooks, and the specimens were hung vertically by insulated bell wire in four horizontal rows. Figure 1 shows the arrangement of the various stands on the roof during the tests. The lower portion of the roof was 2 ft. below the level of the upper portion, but had the same general height of parapet.

One series of specimens in a single surface condition was exposed on each of the test stands. Two of the vertical stands were used for duplicate series in each surface condition, and were exposed at right angles to one another to check possible effects of direction in relation to wind and smoke-drift. However, since considerations of space made it impossible to arrange the stands in such a way that it could be certain that no significant screening occurred from other stands, or higher parts of the building, or that no serious differences existed in relation to the drift of fumes from chimneys and fume stacks, a calibrating series of pickled mild steel specimens was exposed on each stand. There were 12 of these on each vertical stand and 28 on each horizontal stand, spaced out to give an indication of any significant variation across individual stands, as well as between stands.

As a check on the general corrosivity of the atmosphere, three of the standard 4 × 2 × $\frac{1}{8}$-in. ingot-iron pollution specimens as used by J. C. Hudson in his field-test work for the Corrosion Committee[13] were exposed, one on each of the stands, V6 (2 years), V4 (5 years), and H2 (5 years).

Before determining loss of weight all specimens were cleaned free from corrosion product.

Materials (*a*), (*b*), and (*u*), and the ingot-iron

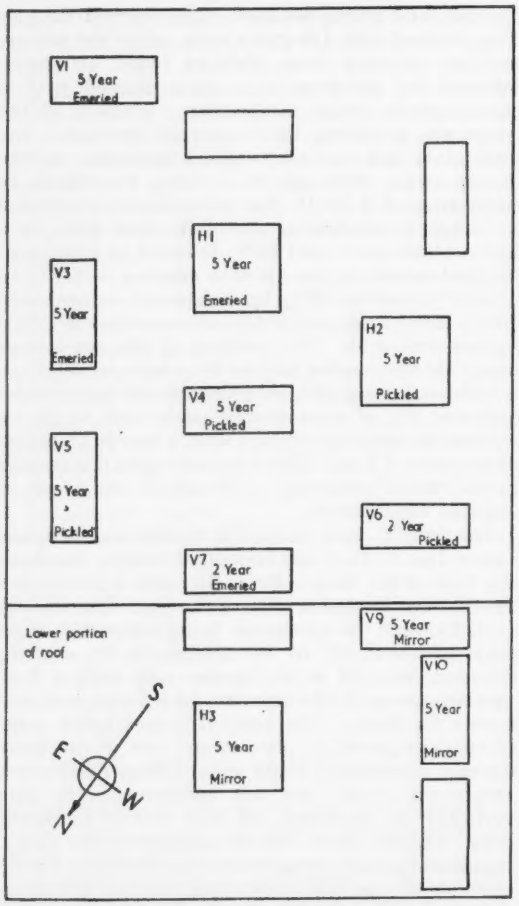


Fig. 1—Arrangement of exposure stands on roof. Prefix " V " indicates specimens hung vertically; prefix " H " specimens hung horizontally; blank spaces indicate stands used for other purposes

samples were freed from rust in S. G. Clarke's solution[13] (*loc. cit.*, p. 60) containing 100 parts of concentrated hydrochloric acid, 2 parts of antimonious oxide, and 5 parts of stannous-chloride crystals. Used at room temperature, the time of de-rusting was of the order of an hour, with a probable loss of metal less than 0·1 g. for (*a*) and (*b*), and less than 0·05 g. for (*u*).

Materials (*c*) to (*u*) were treated in 30% of nitric acid at room temperature with very small losses in metal, the most affected being material (*s*) at 0·04 g., and (*t*) at 0·025 g., followed by (*c*) and (*d*) at 0·006 g.

The aluminium specimens were cleaned in 5% of acetic acid at 40° C., in which they required about 10 minutes' treatment, corresponding to a loss of the order of 0·1 g. on a blank specimen. The probable loss in metal from the zinc specimens was also of the order of 0·1 g.; the treatment in this case being for half-an-hour in 30% of ammonium acetate, at room temperature, based on the recommendations of D.I.N. 4850 (Oct. 1937). The cold 5% of sulphuric acid used for the remaining three non-ferrous materials was also based in D.I.N. 4850, and the losses were of the order of 0·03–0·05 g.

RESULTS OF TESTS

The results for the tests are given in Tables I–V, in which, it will be noted, there are some gaps. Those relating to materials (*e*), (*t*), (*A*), (*D*), and (*E*), for the 2-year tests, are due to the omission of samples of these materials from the shorter-period series. The other omissions were caused by loss of specimens through enemy action in December, 1940. A number of specimens were then dislodged from the stands, and either lost or too badly rusted for re-identification. The remaining specimens appeared to have suffered very little, and it is not considered that the incident will have appreciably affected the reported results.

Tables I and II give the results for the mild-steel specimens used to calibrate the vertical and horizontal stands respectively. Tables IV and V give full details of materials, losses and appearances for the main series. The three ingot-iron pollution samples gave losses of 24·7, 56·9, and 56·7, on stands V6, V4, and H2, respectively.

Figure 2 shows the relative behaviour of some of the more interesting steel samples. The samples were all taken from the vertical mirror-polished series, and were photographed before the removal of rust, but after washing with soapy water to remove the less firmly adherent corrosion products and deposited matter.

Figure 3 illustrates the pitting referred to in Table V (appearance column). In general the pits on the special steels, although numerous, were very small. The illustrations show examples typical of the larger pits from the 14% chromium, 18/8, and 18/8/2½ chromium–nickel–molybdenum steels. The largest pit shown in the view of the 14% chromium steel, at the 100 magnification, was 0·18 × 0·23 mm. across the top, and 0·18 mm. deep, while the pits seen towards the centre of the corresponding view of the 18/8 chromium–nickel steel surface were 0·20 × 0·28 mm. across, and 0·12 mm. deep. The pits on the 18/8/2½ chromium–nickel–molybdenum steel were much smaller, the largest one, illustrated in Fig. 3, being 0·05 × 0·08 mm. across, but only 0·006 mm. deep.

OBSERVATIONS ON RESULTS

GENERAL CORROSIVITY OF THE CONDITIONS

The mean results for mild steel, zinc, and the ingot-iron pollution specimens are given in Table III. They may be compared with the results given by J. C. Hudson[14] for corrosion of such materials at various stations at home and abroad. Relevant figures for the main Sheffield Corrosion Station, and for Sheffield University, have been included in Table III, and it is evident that the atmospheric conditions for the present tests are to be classed as severely industrial, and of a similar order of corrosivity to those at the main Sheffield Corrosion Station. The lower losses for the mild steel, in comparison with Hudson's figures, are probably related to the higher copper content of the present material—0·07% as against 0·02% for the Committee steel.

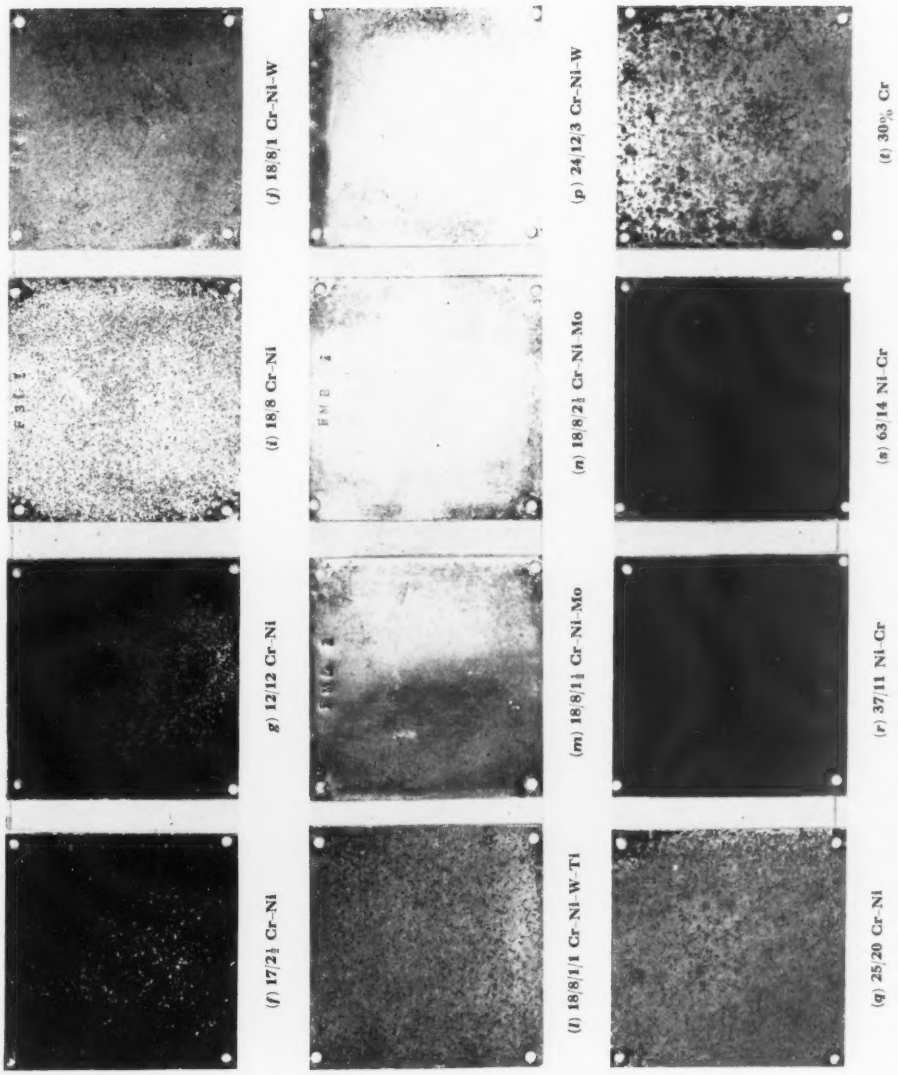
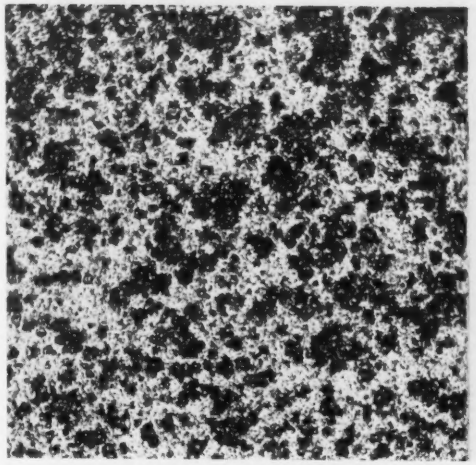
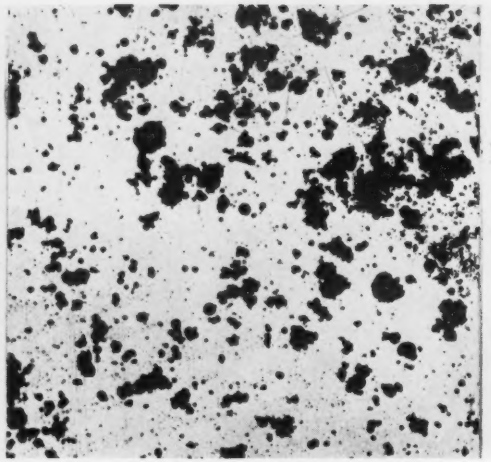


Fig. 2—Appearance of the Cr–Ni steels and 30% Cr steel, cleaned with soap and water after 5 years' vertical exposure

[*Shirley and Truman*
[*To face p.* 370

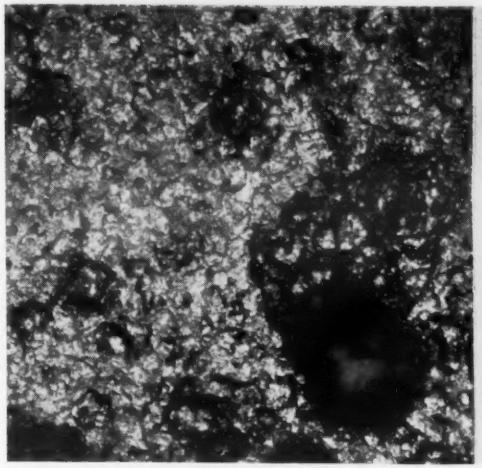


(*d*) 14% Cr (2) × 10

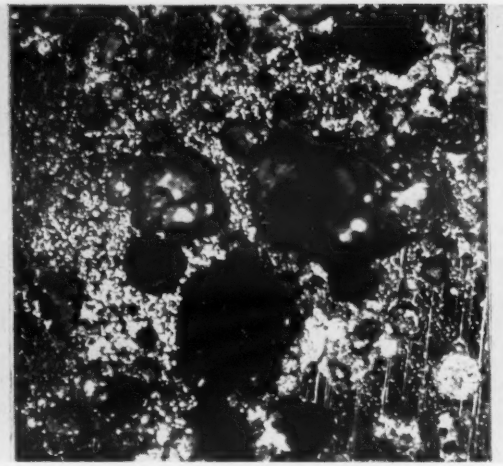


(*i*) 18/8 Cr–Ni × 10

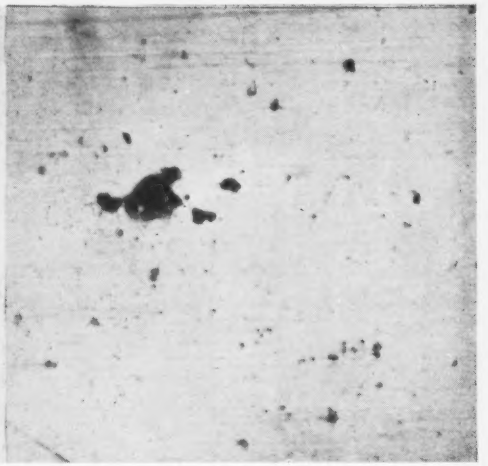
(*n*) 18/8/2½ Cr–Ni–Mo × 10



(*d*) 14% Cr (2) × 100



(*i*) 18/8 Cr–Ni × 100



(*n*) 18/8/2½ Cr–Ni–Mo × 100

Fig. 3—Cleaned surfaces of mirror-polished samples from 5 years' vertical tests, showing distribution and size of pits

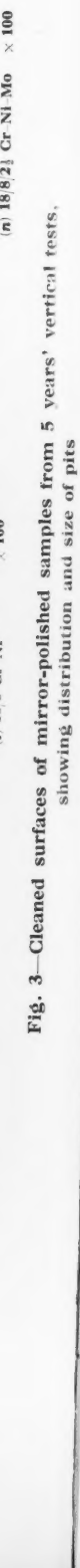


Fig. 3—Cleaned surfaces of mirror-polished samples from 5 years' vertical tests, showing distribution and size of pits

Table I

MILD STEEL SAMPLES FROM VERTICAL STANDS

Stand	Row	Position in Row: Left End	Middle	Right end	Mean	Range
			2 Years' Test			
V7	1	31·1	28·8	28·7	29·9	+1·2 −1·3
	2	28·6	28·8	31·0		
	3	30·6	30·3	30·4		
	4	30·1	29·8	30·2		
			5 Years' Test			
V4	1	73·0	...	74·8	75·6	+2·3 −2·6
	2	77·9	77·6	...		
	3	75·6	75·3	75·3		
	4	...	...	...		
V5	1	79·0	...	79·9	79·6	+2·4 −3·5
	2	80·1	80·9	77·9		
	3	82·0	80·7	79·0		
	4	76·1	...	80·5		
V1	1	...	...	...	70·9	+2·9 −2·2
	2	73·8	72·6	68·7		
	3	70·5	68·9	...		
	4	...	...	...		
V3	1	75·4	72·9	72·8	73·6	+3·2 −2·7
	2	72·6	74·2	74·5		
	3	...	70·9	71·3		
	4	76·8	75·2	72·8		
V9	1	...	...	...	71·1	+1·5 −0·8
	2	...	70·5	72·6		
	3	71·2	71·8	70·3		
	4	72·5	70·9	71·4		
V10	1	...	69·0	70·9	70·2	+3·3 −3·2
	2	...	67·0	70·5		
	3	73·5	72·1	67·5		
	4	70·8	68·6	70·4		

Losses in grams from 4-in. square specimens weighing, initially, approximately 100 g., the overall mean being 73·9 g. for the 5-year specimens.

Table II

MILD STEEL SAMPLES FROM HORIZONTAL STANDS (5 YEARS)

Row	Position in Row: 1 or 2	3 or 4	5 or 6	7 or 8	Mean	Range
			Stand H2			
1	65·9	66·9	67·3	69·3	70·2	+4·7 −5·2
2	72·1	75·9	71·8	70·9		
3	65·0	72·6	70·1	72·5		
4	70·7	70·3	71·1	71·6		
5	65·8	...	69·3	68·6		
6	67·1	71·3	67·1	69·9		
7	70·7	73·8	73·7	74·7		
			Stand H1			
1	67·5	66·8	...	69·9	68·1	+5·8 −8·3
2	72·8	66·9	73·9	65·6		
3	70·9	67·1	69·9	69·7		
4	66·7	69·8	62·4	72·1		
5	...	69·8	65·9	62·6		
6	59·8	71·3	69·3	69·4		
7	64·9	61·0	70·5	72·8		
			Stand H3			
1	65·0	62·6	65·8	62·5	66·2	+8·7 −3·7
2	62·5	64·4	64·5	66·3		
3	65·2	...	67·4	64·1		
4	66·6	66·7	66·7	...		
5	63·8	65·5	63·0	...		
6	...	65·5	...	67·6		
7	74·9	72·0	72·8	66·5		

Losses in grams from 4-in. square specimens weighing, initially, approximately 100 g., the overall mean being 68 2 g.

Table III

MEAN CORROSION RATES INDICATING GENERAL CORROSIVITY OF EXPOSURE CONDITIONS

Measurement in mils/yr.

Test	Mild Steel*	Ingot Iron*	Zinc*
Present Series			
2 years			
Vertical specimens	3·5	5·4	...
5 years			
(*a*) Vertical specimens	3·4	4·9	0·40
(*b*) Horizontal specimens	3·2	4·9	0·46
Tests by J. C. Hudson†			
Sheffield Corrosion Station			
1 year	5·5‡	5·1	0·68
2 years	5·1‡	...	...
5 years	4·4‡	4·4	0·65
Sheffield University			
1 year	...	4·4	0·23
5 years	...	3·7	0·24

* Means of all samples in Tables I and II for mild steel; individual specimens for ingot iron and means for all specimens in Table IV for zinc.

† Atmospheric corrosion tests on unpainted irons and steels: *Journal of the Iron and Steel Institute*, 1943, No. II, pp. 183P and 208P–211P. All specimens were exposed vertically.

‡ The specimens were from a steel with 0·02% of copper and were exposed without removing scale, as against the present series of descaled samples with 0·07% of copper.

Tables I and II give detailed results for the mild-steel calibration specimens. There is, of course, a degree of variability between individual samples, and this is greater for the horizontal than for the vertical stands; but there is no indication of anything of a positional nature sufficient to have an important bearing on the interpretation of the relative resistance of the various steels. The only notable effect, as between stands, is in the rather higher attack for V4 and V5 as compared with the other vertical stands. This suggests the possibility of a slight positional increase in attack on the 5-year vertical pickled samples as compared with the other surface finishes, but since the mean value for the mild steel on these stands, at 78·0, is less than 10% above the average of 71·6 for the other vertical stands, it is not a matter of much practical significance in the present study.

EFFECT OF VARIOUS FACTORS ON THE RESPONSE OF THE STEELS

Effect of Composition

Composition was, of course, the major factor under consideration. In Table VI, the detailed losses given in Table V are grouped as means for the 2-year vertical, 5-year vertical, and 5-year horizontal series, respectively, after recalculation on a basis of 100 for mild steel. The resistance to corrosion is also indicated in order of merit. It is seen that the correspondence between the three groups is very good. The order of merit is the same within a difference of two places throughout the 5-year tests, and the only exception to this, when the 2-year tests are included, is with

steel (*d*) with a difference of 4 places, and steel (*q*) with a difference of 3 places.

The low-alloy nickel–chromium–molybdenum steel (*b*) shows a very considerable improvement over mild steel, at about a quarter of the loss. High-speed steel (*u*) also suffered a loss of this order. This is followed by a further considerable improvement to losses of only about 5% of those for mild steel, materials in this group including the 14% and 18% chromium steels (*c*, *d*, and *e*), the 17/2½ and 12/12 chromium–nickel steels (*f* and *g*), the 18/8 chromium–manganese steel (*h*), and the 37/11 and 63/14 nickel–chromium steels (*r* and *s*). Next come most of the remaining chromium and chromium–nickel steels with losses in the 1–3% range, this group including the 18/8 chromium–nickel steels, with nominal 1% additions of tungsten, titanium, and aluminium (*i*, *j*, *k*, *l*, and *o*), the 25/20 chromium–nickel steel (*q*) and the 30% chromium steel (*t*). There is a suggestion that both tungsten and titanium additions give some improvements, and aluminium some worsening of the resistance within this series.

The remaining three steels (*m*, *n*, and *p*) bring out clearly the very great benefit possible from molybdenum or tungsten additions. Steels (*n*) and (*p*), with about 3% additions of these elements respectively, remained almost unaffected, with losses of the order of only one thousandth that of mild steel. Steel (*m*) with 1½ molybdenum showed an intermediate effect. Considerable improvement in the case of molybdenum addition was expected in view of its very considerable effect in improving the resistance of the 18/8 chromium–nickel steel towards attack by many acids. On the other hand, similar high resistance in the case of the 3% tungsten-bearing steel (*p*) would not have been inferred from a consideration of the general results for acid resistance, the improvement over plain 18/8 chromium–nickel steel in these corrosive media being not only much smaller, but actually less than for 18/8/1 chromium–nickel–titanium steel. This is illustrated, for example, by the following losses of weight (g./sq. cm.) for 24 hour tests in sulphuric acid at 20° C.:

Concentration of H_2SO_4 (Wt/Wt), %	18/8 Cr–Ni Steel	18/8/1 Cr–Ni–Ti Steel	18/8/3 Cr–Ni–Mo Steel	23/12/3 Cr–Ni–W Steel
5	·0038	·0005	·0000	·0007
2·5	·0016	·0001	·0000	·0005
1	·0011	·0001	·0000	·0003
0·5	·0006	·0001	·0000	·0002
0·25	·0000	·0000	·0000	·0002

However, the effect appears to be quite definite for this composition, and it will be seen later, when comparing the results

Table IV

COMPOSITION OF MATERIALS FOR FULL SERIES

Ref.	Material	Composition													Condition	Ref.
		C	Si	Mn	Cr	Ni	Cu	W	Ti	Mo		Ga				
a	Mild steel	0·20	0·21	0·55	0·06	0·13	0·07	Nil	..	Nil	..	18			A.C. 920° C.	*a*
b	Ni–Cr–Mo low-alloy steel	0·30	0·22	0·68	1·18	3·01	0·10	Nil	..	0·64	..	18			O.Q. 850, T. 620° C.	*b*
c	14 Cr (1) steel (F.C.)	0·25	0·44	0·32	13·51	0·26	0·04	Nil	Nil	Nil	..	18			O.Q. 950, T. 750° C.	*c*
d	18 Cr (2) steel (F.I.)	0·11	0·27	0·24	14·02	0·22	0·04	Nil	Nil	Nil	..	18			O.Q. 950, T. 750° C.	*d*
e	17/21 Cr–Ni steel (S.80)	0·06	0·47	0·38	17·30	0·13	0·03	Nil	Nil	0·01	..	22			A.C. 750° C.	*e*
f	12/12 Cr–Ni steel (D.D.Q.)	0·14	0·18	0·24	16·88	2·66	0·05	Nil	Nil	Nil	..	16			F.C. 850 and 650° C.	*f*
g	18/8 Cr–Mn steel	0·12	0·31	0·30	13·02	12·23	0·05	Nil	Nil	0·01	..	17			A.C. 1050° C.	*g*
h	18/8 Cr–Ni steel	0·13	0·56	0·28	18·39	0·24	0·14	0·03	0·61	Nil	..	20			,,	*h*
i	18/8/1; Cr–Ni–W steel	0·06	0·39	0·39	18·02	7·96	0·08	Nil	Nil	0·03	..	19			,,	*i*
j	18/8/1; Cr–Ni–Ti steel (F.D.P.)	0·15	0·70	0·35	18·00	8·03	0·03	0·76	Nil	0·02	..	17			,,	*j*
k	18/8/1; Cr–Ni–W–Ti steel	0·14	0·63	0·33	18·21	8·23	0·04	Nil	0·65	Nil	..	18			,,	*k*
l	18/8/1½; Cr–Ni–Mo steel (F.M.L.)	0·05	0·68	0·31	18·87	8·34	0·04	0·68	0·72	0·03	..	17			,,	*l*
m	18/8/2½; Cr–Ni–Mo steel (F.M.B.)	0·05	0·75	0·32	17·85	9·46	0·05	Nil	Nil	1·35	..	18			,,	*m*
n	18/8/1½; Cr–Ni–Ti–Al steel (Stayblade Max)	0·16	0·73	0·42	18·66	8·11	0·03	Nil	0·84	0·01	1·31*	12			,,	*n*
o	24/12/3; Cr–Ni–W steel (HR Crown Max)	0·23	1·66	0·45	23·94	12·05	0·04	3·35	Nil	0·01	..	18			,,	*o*
p	25/20; Cr–Ni steel (Immaculate 5)	0·11	1·26	0·42	24·58	20·89	0·03	Nil	Nil	0·01	..	18			,,	*p*
q	37/11; Ni–Cr Steel (Macloy B)	0·30	0·28	1·16	11·40	37·65	0·02	Nil	Nil	Nil	..	18			,,	*q*
r	63/14; Ni–Cr Steel (Vikro)	0·11	0·71	1·24	13·60	63·50	0·03	Nil	Nil	Nil	..	20			,,	*r*
s	30 Cr steel (Pyrista)	0·35	0·75	0·89	30·39	0·28	0·03	Nil	Nil	0·03	..	19			,,	*s*
t	High-speed steel	0·62	0·23	0·19	4·28	0·12	<0·01	18·21	Nil	0·07	1·14†	18			F.C. 900° C.	*t*
		Cu	Sn	Pb	P	Zn	As	Ni	Mn	Si	Fe					
A	Aluminium	<0·01	..	Nil	..	Nil	..	Nil	0·007	0·24	0·46	18			Commercial supply	*A*
B	Copper	99·92	..	..	..	..	..	..	..	..	..	18			,,	*B*
C	Phosphor Bronze	95·75	3·53	0·14	0·066	0·20	0·011	Nil	..	..	..	18			,,	*C*
D	54/44, Cu–Ni	58·28	Nil	Nil	..	..	0·004	43·86	0·032	0·07	0·05	16			,,	*D*
E	Zinc	<0·005	..	0·88	..	..	..	..	<0·005	..	<0·005	18			,,	*E*

* Aluminium † Vanadium

Table V

RESULTS FOR FULL SERIES OF MATERIALS*

Ref.	Material	2-Yr. Tests: Vertical Stands			5-Yr. Tests: Vertical Stands							5-Yr. Tests: Horizontal Stands				Appearance After Cleaning 5-Year Samples	Ref.
		Pickled	Emeried	Mean	Pickled		Emeried		Mirror polished		Mean	Pickled	Emeried	Mirror polished	Mean		
		V6	V7		V4	V5	V1	V3	V9	V10		H2	H1	H3			
a	Mild steel†	..	..	29·9	..	..	..	..	..	..	73·9	..	..	..	68·2	General attack with "honeycombing"	*a*
b	Ni-Cr-Mo low-alloy steel	9·42	8·51	8·96	..	18·02	..	16·60	..	17·25	17·29	22·44	23·38	19·47	21·76	General attack with "honeycombing"; tendency for pitting on polished samples	*b*
c	14 Cr (1) steel (F.G.)	2·76	1·93	2·34	..	5·97	..	6·61	4·87	4·06	5·38	3·97	5·15	3·59	4·24	Almost complete loss of reflectivity; very numerous, very small pits	*c*
d	14 Cr (2) steel (F.I.)	0·90	1·17	1·03	..	..	3·05	4·06	3·66	4·43	3·80	2·05	2·75	2·96	2·59	As for (*c*) but rather fewer and larger pits on horizontal samples	*d*
e	18 Cr steel	..	..	..	2·27	2·72	3·35	2·93	2·31	2·73	2·72	..	..	..	..	Considerable loss of reflectivity; very numerous small pits	*e*
f	17/2½ Cr-Ni steel (S.80)	0·85	1·37	1·11	..	2·48	3·65	4·46	3·32	..	3·48	1·17	2·78	2·64	2·20	Very considerable loss of reflectivity, tendency for numerous very small pits	*f*
g	12/12 Cr-Ni steel (D.D.Q.)	0·72	1·19	0·95	2·70	3·79	2·91	3·08	3·42	3·22	3·19	1·35	2·10	1·21	1·55	General etching with considerable loss of reflectivity, except H3 sample; numerous small pits	*g*
h	18/8 Cr-Mn steel	1·09	..	1·09	..	3·68	2·42	3·68	3·39	..	3·27	1·28	2·46	1·95	1·90	Considerable loss of reflectivity with fairly numerous small pits	*h*
i	18/8 Cr-Ni steel	0·48	0·59	0·53	2·08	1·03	1·59	2·93	1·32	1·16	1·69	0·64	2·53	0·83	1·33	Some loss of reflectivity with vertical, and much more with horizontal samples; very numerous small pits	*i*
j	18/8/1, Cr-Ni-W steel	0·30	0·48	0·39	1·73	0·64	1·62	1·25	0·84	0·59	1·11	0·30	1·22	0·44	0·65	Less reflectivity loss than for (*i*) except almost complete loss on H1; pits fewer but rather larger than for (*i*)	*j*
k	18/8/1, Cr-Ni-Ti steel (F.D.P.)	0·34	0·54	0·44	1·50	0·91	..	1·00	1·70	0·99	1·42	0·43	1·45	0·73	0·87	Similar to (*i*)	*k*
l	18/8/1/1, Cr-Ni-W-Ti steel	0·39	0·51	0·45	1·13	0·96	1·13	0·98	1·03	1·45	1·11	0·39	1·29	0·55	0·74	Generally similar to (*i*) but only small loss of reflectivity on horizontal samples	*l*
m	18/8/1¼, Cr-Ni-Mo steel (F.M.L.)	0·09	0·17	0·13	0·28	0·15	0·19	0·31	0·14	0·10	0·19	0·06	0·17	0·16	0·13	Considerably less affected than (*i*) but appreciable loss of reflectivity on horizontal samples	*m*
n	18/8/2¼, Cr-Ni-Mo steel (F.M.B.)	0·01	0·03	0·02	0·01	0·00	0·03	0·06	0·01	0·02	0·02	0·00	0·12	0·09	0·07	Very slight pitting, and loss of reflectivity, except for appreciable reflectivity loss on horizontal samples	*n*
o	18/8/1/1¼, Cr-Ni-Ti-Al steel (Stayblade Max)	0·78	0·98	0·88	2·29	..	2·80	2·54	..	2·27	2·48	1·21	2·12	1·24	1·52	Very numerous small pits on vertical samples; general loss of reflectivity and numerous rather larger pits on horizontal samples	*o*
p	24/12/3, Cr-Ni-W steel (HR Crown Max)	0·03	0·03	0·03	..	0·06	0·10	..	0·08	0·06	0·08	0·10	0·08	0·00	0·06	Between (*m*) and (*n*)	*p*
q	25/20, Cr-Ni steel (Immaculate 5)	0·27	0·52	0·39	1·66	1·46	1·44	1·82	1·62	1·42	1·57	0·44	1·22	1·01	0·92	Similar to (*i*)	*q*
r	37/11, Ni-Cr steel (Macloy B)	2·00	1·43	1·71	3·48	3·98	3·83	..	3·60	3·50	3·68	3·48	3·09	2·78	3·12	Mainly general attack with almost complete loss of reflectivity	*r*
s	63/14, Ni-Cr steel (Vikro)	1·22	1·20	1·21	3·42	3·49	..	2·77	2·86	2·76	3·56	2·55	2·77	2·77	2·70	Similar to (*r*)	*s*
t	30 Cr steel (Pyrista)	..	..	..	..	0·84	1·50	..	..	1·75	1·36	0·45	0·66	0·54	0·55	Numerous small pits, with considerable loss of reflectivity on horizontal samples	*t*
u	High-speed steel	6·29	9·12	7·70	12·70	10·22	..	18·19	12·92	10·10	12·83	11·49	16·21	17·18	14·96	General attack with very uneven surface	*u*
A	Aluminium	..	..	..	3·96	3·88	2·95	3·06	2·53	..	3·28	3·15	..	1·58	2·36	Very rough except for appreciable residual reflectivity on upper surface of H3 sample	*A*
B	Copper	2·10	2·56	2·33	3·29	3·61	4·02	3·99	3·59	3·71	3·72	3·29	4·30	3·79	3·82	General attack; smooth surface	*B*
C	Phosphor bronze	1·96	2·26	2·11	4·31	3·85	3·43	3·94	..	..	3·90	4·31	4·09	4·08	4·16	As (*B*)	*C*
D	54/44, Cu-Ni	..	..	..	9·20	9·17	8·20	8·93	8·92	8·47	8·82	8·95	8·92	8·50	8·79	As (*B*)	*D*
E	Zinc	..	..	..	7·60	8·30	7·31	7·71	8·19	7·28	7·71	9·30	8·98	8·63	8·97	General attack with some roughness, particularly on horizontal samples	*E*

* The results are given as total loss in weight in grammes after freeing from corrosion products, all samples being 4 × 4 in.
† Mean results for the full series of pickled samples from the various stands. (*See* Tables I and II)

* Aluminium † Vanadium

Table VI

COMPARISON OF MEAN LOSSES AND ORDER OF MERIT FOR FULL SERIES OF STEELS

Material	Mean Loss Relative to Mild Steel = 100			Order of Merit		
	2-Yr. V* Stands	5-Yr. V Stands	5-Yr. H† Stands	2-Yr. V Stands	5-Yr. V Stands	5-Yr. H Stand
(*a*) Mild steel	100	100	100	21	21	21
(*b*) Ni–Cr–Mo steel	30·0	23·5	31·9	20	20	20
(*c*) 14 Cr (1) steel	7·8	7·3	6·2	18	18	18
(*d*) 14 Cr (2) steel	3·4	5·2	3·8	13	17	15
(*e*) 18 Cr steel	...	3·7	...	11^{+}_{+}	11	11^{+}_{+}
(*f*) 17/2½ Cr–Ni steel	3·7	4·7	3·2	15	14	14
(*g*) 12/12 Cr–Ni steel	3·2	4·3	2·3	12	12	12
(*h*) 18/8 Cr–Mn steel	3·6	4·5	2·8	14	13	13
(*i*) 18/8 Cr–Ni steel	1·8	2·3	2·0	9	9	9
(*j*) 18/8/1 Cr–Ni–W steel	1·3	1·5	1·0	4	4	5
(*k*) 18/8/1 Cr–Ni–Ti steel	1·5	1·9	1·3	7	7	7
(*l*) 18/8/1/1 Cr–Ni–W–Ti steel	1·5	1·5	1·1		5	6
(*m*) 18/8/1½ Cr–Ni–Mo steel	0·43	0·26	0·19	3	3	3
(*n*) 18/8/2½ Cr–Ni–Mo steel	0·07	0·03	0·10	1	1	2
(*o*) 18/8/1/1½ Cr–Ni–Ti–Al steel	2·9	3·4	2·3	10	10	10
(*p*) 24/12/3 Cr–Ni–W steel	0·10	0·11	0·09	2	2	1
(*q*) 25/20 Cr–Ni steel	1·3	2·1	1·3	5	8	8
(*r*) 37/11 Ni–Cr steel	5·7	5·0	4·6	17	16	17
(*s*) 63/14 Ni–Cr steel	4·0	4·9	4·0	16	15	16
(*t*) 30 Cr steel	...	1·9	0·81	6^{+}_{+}	6	4
(*u*) High-speed steel	25·7	17·5	21·9	19	19	19

* V = Vertical † H = Horizontal ‡ Assumed position: no actual test

with those from the 1931–32 series (Table VIII), that there, also, the 24/12/3 chromium–nickel–tungsten steel showed a similar resistance to the chromium–nickel–molybdenum type.

Effect of Surface Condition

The only clearly marked trend, based on surface condition, is the higher losses for the emeried samples of the more resistant materials, as compared with the other two surface finishes. This effect is brought out in Table VII, where results are summarized for the ten most resistant chromium–nickel steels. It is small in the case of the vertical stands, but considerable for the horizontal stands.

Effect of Angle of Exposure

The effect of angle of exposure is apparent only in the lower losses suffered by the pickled and mirror-finished samples of the more resistant materials exposed on the horizontal frames as compared with the vertical frames. This is brought out by the summary figures in Table VII. By contrast, the losses for the emeried samples were of the same order for both types of stand.

Effect of Time of Exposure

Since the results summarized in Table III show the amount of attack on mild steel to be practically linear with time, the relative losses given in Table VI can be used for direct comparison of the rates over 2-year, and 5-year, periods for the vertical samples of the other materials. The figures do not suggest any notable variations with time as between these two periods for vertical samples.

In the case of the horizontal frame results, comparison is possible between the present 5-year tests and the 1931–32 tests in respect of emeried samples of several of the compositions tested. The relevant results are given in Table VIII and show a general tendency for a fall in rate of attack during the earlier stages of exposure.

The results of the 1931–32 series bring out the excellent resistance of the 24/12/3 chromium–nickel–tungsten material and its similarity to the 18/8/3 chromium–nickel–molybdenum steel, as already discussed in considering the effects of compositions. Also, by expressing the losses in Table VIII in terms of g./sq.in./yr., direct comparison is possible with the American figures quoted in the introduction. The present losses are seen to be of a definitely higher order, indicative of considerably greater corrosivity in the conditions of exposure.

RESULTS FOR NON-FERROUS MATERIAL

Tables IV and V include the results for the five non-ferrous materials tested. The only noticeable trends regarding the effect of surface preparation or type of exposure stands are with aluminium, for which there is some indication of higher losses for the acid pickled samples as compared with the polished samples, and for vertical-frame polished specimens as against the corresponding horizontal-frame samples.

There is an indication of some fall in the corrosion rate with time for the copper and phosphor bronze, the vertical frame losses in 5 years being not quite double those in 2 years.

With regard to the general level of attack of these non-ferrous materials, the losses for zinc have already been shown to be in line with the Corrosion Committee's general experience with atmospheric pollution samples of this metal. It is also interesting to compare

Table VII

MEAN EFFECT OF SURFACE CONDITION AND ANGLE OF EXPOSURE FOR TEN MOST RESISTANT CHROMIUM–NICKEL STEELS

Type of surface	Mean losses in grammes		
	2-yr. vertical stands	5-yr. vertical stands	5-yr. horizontal stands
Pickled	0·35	1·24	0·49
Emeried	0·50	1·30	1·23
Mirror-polished	...	1·11	0·63

Table VIII

COMPARISON OF RESULTS FOR EMERIED HORIZONTAL-FRAME SAMPLES

Series (*a*): 1931–32 Series (*b*): 1938–43

Material	Series	Composition %									Loss, g./sq. in./yr.		
		C	Si	Mn	Cr	Ni	Cu	W	Mo		month	1 yr.	5 yrs.
Mild steel	*a*	0·21	0·04	0·61	Nil	0·04	0·02	...	...		1·470	0·689	...
	b	0·20	0·21	0·55	0·06	0·13	0·07	Nil	Nil		...	...	0·412*
Ni–Cr–Mo Low-alloy steel	*a*	0·33	0·25	0·58	1·12	3·00	...	...	0·50		0·855	0·227	...
	b	0·30	0·22	0·68	1·18	3·01	0·10	Nil	0·64		...	...	0·127
14 Cr (1)	*a*	0·27	0·43	0·29	13·69	0·27	...	...	...		0·078	0·051	...
	b	0·25	0·44	0·32	13·51	0·28	0·04	Nil	Nil		...	...	0·031
14 Cr (2)	*a*	0·14	0·27	0·35	14·29	0·19	...	...	...		0·092	0·044	...
	b	0·11	0·27	0·24	14·02	0·22	0·04	Nil	Nil		...	...	0·017
17/2½ Cr–Ni	*a*	0·13	0·28	0·15	17·98	1·82	...	...	...		0·021	0·009	...
	b	0·14	0·18	0·24	16·88	2·66	0·05	Nil	Nil		...	...	0·017
12/12 Cr–Ni	*a*	0·13	0·45	0·27	12·92	12·41	...	...	...		0·035	0·010	...
	b	0·12	0·31	0·30	13·02	12·23	0·05	Nil	0·01		...	...	0·013
18/8 Cr–Ni	*a*	0·20	0·35	0·28	18·14	7·62	...	...	...		0·014	0·005	...
	b	0·06	0·39	0·39	18·02	7·96	0·08	Nil	0·03		...	...	0·015
18/8/1 Cr–Ni–W	*a*	0·15	0·73	0·34	18·29	8·96	...	0·69	...		0·007	0·005	...
	b	0·15	0·70	0·35	18·00	8·03	0·03	0·76	0·02		...	...	0·007
18/8/3 Cr–Ni–Mo	*a*	0·14	0·70	0·40	18·00	8·00	...	...	3·25		0·014	0·002	...
	b	0·05	0·75	0·32	18·37	8·21	0·04	Nil	2·62		...	...	0·0006
24/12/3 Cr–Ni–W	*a*	0·12	0·60	0·40	23·00	11·50	...	3·00	...		0·007	0·002	...
	b	0·23	1·66	0·45	23·94	12·05	0·04	3·35	0·01		...	...	0·0006
High-speed steel	*a*	0·70	0·27	0·34	3·59	0·11	...	15·09	...	0·66 V	1·280	0·306	...
	b	0·62	0·23	0·19	4·28	0·12	2·01	18·21	0·07	1·14 V	...	...	0·097

* Pickled samples in this case only

the figures for copper and zinc with those found by J. C. Hudson in 1-year tests at Birmingham[15] in 1927–28. The mean figures from the present 5-year vertical tests are 570 and 1090 mg./100 sq. cm./yr. respectively, as compared with Hudson's figures of 357 and 708 in the Birmingham tests, which is in line with the very high corrosivity of the present conditions.

As compared with the ferrous materials, the losses for copper and aluminium are seen to be considerably greater than those for most of the chromium–nickel steels. Although in some cases this may to some extent be offset by a pitting tendency with the steels, the very great superiority of steels (*n*) and (*p*) over all the other materials tested is clearly demonstrated for these severely industrial conditions of exposure, their losses being of the order of only a hundredth of those of the non-ferrous materials.

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An Examination of the Thiocyanate Porosity Test for Tinplate

By J. Pearson, Ph.D., M.Sc., F.R.I.C., and W. Bullough, B.Sc., A.R.I.C.

SYNOPSIS

The thiocyanate porosity test for tinplate has been found to require modification. Suggestions are made in respect of the preparation of the test solutions, the cleaning of the tinplate specimens, and the estimation of dissolved iron, and results are presented to indicate that the method is then suitable for providing a quantitative estimate of the extent of discontinuities in the tin coating on commercial hot-dipped tinplate.

PROCEDURES such as the ferricyanide and hot-water tests[1] for estimating the porosity or lack of continuity of tin coatings on tinplate are reliable but of limited value because they indicate only the *number* and distribution of discontinuities. The thiocyanate test[2] does not provide a record of the number or distribution of pores; instead the reagent employed attacks the iron exposed at the base of pores and scratches, and the amount of iron salts found in the solution after a specified time of treatment is an indication of the *area* of base metal exposed.

The experimental directions[2] are as follows: "The specimen (8 cm × 6 cm) is degreased cathodically in cold 1% sodium carbonate, and the edges are 'stopped-off' with hard paraffin or Seekay wax. It is then placed in a 300-cc tall beaker containing 250 cc of a solution of composition: ammonium thiocyanate 20 g, glacial acetic acid 10 g, and hydrogen peroxide (20 vol) 10 g/litre. The exposed iron is attacked by the acetic acid, the action being accelerated by the hydrogen peroxide, which also oxidizes the ferrous ions to the ferric state, producing a red coloration with the thiocyanate. After 15 min, the specimen is removed and the amount of iron in solution is determined colorimetrically, either by means of a tintometer or by comparison with standards in a Nessler cylinder. The result is reported as milligrammes of iron dissolved per square decimetre of surface, allowance being made for the area stopped-off and including both sides of the plate. It was found that the amount of iron dissolved varied with the concentration of acetic acid and ammonium thiocyanate, but that the concentration of hydrogen peroxide, provided that it was sufficient to keep the iron fully oxidized, had no effect."

It was decided to investigate how closely the above directions must be observed, and whether any conditions not specified were necessary, to obtain accurate and reproducible results. All colour comparisons and measurements were made using a Hilger Spekker photo-electric absorptiometer with blue–green filters (No. 603) to eliminate personal errors involved in visual matching.

CLEANING

It was expected that the efficiency with which grease, etc., was removed from a specimen would influence the results obtained, but the amount of iron dissolved from tinplate specimens cathodically treated till free from 'water-break,' was less than that from those cleaned in trichlorethylene. This was unexpected, and presumably was due to occlusion of hydrogen. Specimens placed in boiling water after cathodic cleaning evolved gas and then gave normal values when tested for porosity. Supplementary tests showed that 3-min boiling would remove the effect of occluded gas.

Although the gas may be removed by hot-water treatment, it is considered that tinplate for porosity testing should not be cleaned cathodically. The nature of the resulting surface will not be precisely known, since reduction of tin oxide may have occurred and the hot-water treatment may have produced incipient rusting at discontinuities in the coating. In any case, it is not certain that cathodic treatment is without effect on such materials as iron oxides which may be present at the base of pores. Thus the number of pores assessed by the ferricyanide method on tinplate specimens scrupulously cleaned with trichlorethylene has been found to be only about one-third of that found on the same specimens after an additional cathodic alkali treatment for 2 min at 3 amp/sq.ft. No further increase in pore count was noted when the cathodic treatment was prolonged beyond 2 min. Some pores already showing before cathodic treatment were seen to be larger after the treatment. This suggests that normally unreactive iron oxide at the base of pores is reduced by the cathodic treatment. In any case, it is unlikely that the tinplate surface after cathodic cleaning and hot-water immersion will be simply the original surface with the grease removed.

The question arises as to whether cleaning should be employed before testing for porosity, and, if so, to what extent. Tinplate is generally used for the fabrication of boxes, food containers, etc., in the as-received condition; *i.e.*, palm-oil residues, if any, are not specifically removed. Some of the grease will be removed during the fabricating processes and it appears justifiable to use specimens which have been degreased as far as possible in an organic solvent. This type of cleaner is preferred as it is less likely to change the physical or chemical condition of the tin surface or its associated defects. Experiments have shown that essentially all palm-oil, as such, is removed by immersing the specimens in

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Dr. Pearson and Mr. Bullough are engaged in research at the B.I.S.R.A. Laboratories, Sketty Hall, Singleton Park, Swansea.

boiling trichlorethylene, followed by treatment in the vapour of the same solvent to remove any traces of grease left on the specimens by drag-out.

STABILITY OF TEST SOLUTIONS

The colour density of the red solutions from the test does not decrease significantly during the course of at least one hour, though such solutions, when allowed to stand for longer periods, exhibit a loss of red colour, a slight turbidity, and a yellow precipitate. Provided that the colour measurements are made without undue delay, the actual period of standing is thus not critical.

When tinplate specimens were immersed in unused test solutions which had been allowed to stand for some hours, the red colour developed was only slight and in some instances negligible. When the specimens were removed, washed, and replaced in freshly prepared solutions, rapid colour development ensued. It was thus obvious that the original test solutions had deteriorated. Analysis of aged solutions showed that deterioration was due to reduction of hydrogen peroxide by thiocyanate, the products being cyanide and sulphate, at least in the early stages of the reaction. Approximately 30% of the original peroxide was reduced at room temperature in 15 min.

The following tests were carried out to ascertain how long a solution could be kept before deterioration was sufficient to induce low porosity results. It was found that the amounts of iron dissolved from tinplate specimens by three successive treatments in fresh solutions were not significantly different, particularly if the individual tests were curtailed to 4 min. A specimen was therefore immersed for this period in a freshly prepared solution, and then removed, washed, and replaced in a solution which had been allowed to stand for some time, and of which the hydrogen peroxide concentration was determined just before the specimen was immersed. At the end of a further 4 min it was again removed, washed, and placed in a fresh solution containing only as much peroxide as the second solution. Alternatively, the third test was performed in the solution which had been allowed to stand, and the second test with a fresh solution of the same peroxide concentration. The results of four such sequences are given below :

Test		Age of Solution, hr.	Hydrogen Peroxide Concn., % of Nominal	Absorptiometer Reading
(1)	...	0	100	6·1
(2)	...	1	46	5·9
(3)	...	0	46	6·0
(4)	...	0	100	8·3
(5)	...	2	31	6·1
(6)	...	0	31	8·5
(7)	...	0	100	8·3
(8)	...	0	25	7·1
(9)	...	2¾	25	6·3
(10)	...	0	100	6·8
(11)	...	0	16	5·6
(12)	...	4¾	16	3·7

Reduced coloration in an aged solution is produced by two factors : The first is simply the lower concentration of hydrogen peroxide (compare tests (3) and (1), tests (6) and (4), tests (8) and (7), and tests (11) and (10)). The second factor is the presence of the products of reaction of thiocyanate and peroxide, which may interfere with either the primary dissolution process or the development of the red thiocyanate colour (compare tests (5) and (4), tests (9) and (8), and tests (12) and (11)). To overcome the effect of interaction of the thiocyanate and peroxide, the test could be conducted in a mixture of dilute acetic acid and hydrogen peroxide, and the thiocyanate added as solid or concentrated solution, after the specimen had been removed. With this method the amount of iron dissolved from the tinplate was very small ; it is therefore preferable for the solutions to be made up freshly for each test from separate stock solutions of ammonium thiocyanate, acetic acid, and hydrogen peroxide.

EFFECT OF TEMPERATURE

It was expected that the rate at which iron was dissolved by the acetic-acid/hydrogen-peroxide/ammonium-thiocyanate mixture would, like most chemical reactions, be dependent upon the temperature at which the test was carried out. To ascertain the effect of temperature, a rectangular sheet of tinplate was cut into nine pieces, each 8 cm × 6 cm, and these were then tested in groups of three for 15 min in solutions maintained at 17°, 21°, and 26° C, respectively. The solutions were freshly prepared and had been quickly warmed to these temperatures immediately before the immersion of the specimens. At the end of each test the colours of the solutions were measured, and were found to be :

	17° C	21° C	26° C
	0·64	0·78	0·68
	0·54	0·54	0·94
	0·66	0·50	0·49
Mean	0·61	0·61	0·70

These results indicate that temperature is not critical ; even the high mean obtained at 26° C is not significantly different from those at 17° and 21° C. The temperature coefficient of unity is to be ascribed to the fact that although increasing temperature tends to accelerate the dissolution rate of iron, this is countered by an enhanced rate of reaction between peroxide and thiocyanate, which results in a decreased peroxide concentration and an increased concentration of the reaction products—two factors which produce a reduction in the red colour developed in the test.

EFFECT OF SCRATCHES

To observe the effect of scratches on apparent porosity, several specimens, cleaned and waxed, were immersed in test solutions and the rate at which iron was dissolving was noted. The specimens were then quickly removed, scratched with a tungsten carbide point, and replaced. Although iron now dissolved copiously from the scratches, the rate at which it dissolved from the original pores was in all instances seen to be much reduced. The inference from this observation is that the actual amount of iron dissolved during a test is not simply proportional to the area of the base metal exposed through pores, scratches, etc. As far as scratches are concerned, this is not a serious defect, because such heavy damage is not likely to occur on tinplate,

and if it were, its presence would be readily detected and the results ignored. The suggestion that iron dissolved is not simply proportional to the area of exposed base metal was confirmed by the fact that, while the amount of iron dissolved from tinplate of low porosity is essentially proportional to the number of pores, as revealed by the ferricyanide test, with tinplate of higher porosity, the iron dissolved is less than would be expected on the basis of the pore count by the ferricyanide method. The relationship between iron dissolved and pore count is linear over the range of coating weights covered by commercial hot-dipped tinplate as used for food packing. The influence of pore area on iron dissolution is being studied and will be reported upon later.

COLOUR MEASUREMENT

The dilute stock iron solutions used for preparing comparison standards usually contain free mineral acid, whereas the coloured test solutions contain only acetic acid. The colour of ferric thiocyanate is influenced by mineral acid concentration. Before making colour comparisons, sufficient sulphuric acid should therefore be added to the test solutions and the standards to ensure maximum development of colour ; 2 ml of the concentrated acid added to the 250 ml of solution are adequate.

The colour is also influenced by concentrations of ammonium thiocyanate and acetic acid, but there should be no difficulty in keeping these concentrations constant. Stock solution should be analysed if any doubt exists on this point.

RECOMMENDED PROCEDURE FOR POROSITY TESTING

The following procedure is recommended for porosity testing. The specimens should consist of tinplate panels, approximately 8 cm × 6 cm, marked for identification, if necessary, by scribing near one short edge.

Reagents

(i) *Ammonium Thiocyanate*—An aqueous solution of A.R. ammonium thiocyanate, $0{\cdot}66 \pm 0{\cdot}007N$, as determined by titration with mercuric nitrate.[3]

(ii) *Acetic Acid*—A.R. glacial acetic acid diluted to a strength of $0{\cdot}435 \pm 0{\cdot}0045N$, as determined by titration with $N/5$ sodium hydroxide, using phenolphthalein as indicator.

(iii) *Hydrogen Peroxide*—Concentrated hydrogen peroxide diluted to ' 1 volume,' and checked to within 1·0% by titration with $N/5$ potassium permanganate, in presence of sulphuric acid.

(iv) *Ferric Iron*—A.R. ferrous ammonium sulphate (0·7022 g) dissolved in 100 ml of distilled water and acidified with 5 ml of concentrated sulphuric acid. Slight excess hydrogen peroxide is added and the solution is boiled to expel the excess, and then cooled, and diluted to 1 litre. (One millilitre of this solution ≡ 0·1 mg of iron.) For estimation of very small amounts of dissolved iron, dilute this solution fivefold, when 1 ml ≡ 0·02 mg of iron.

If a large batch of tests is to be carried out, it may be advantageous to prepare stronger stock solutions to be diluted appropriately just before the test solutions are made up.

Degreasing

Place the specimens in a suitable wire-frame basket and immerse for 15 min in boiling, dry, acid-free, redistilled trichlorethylene. The solvent is conveniently held in a tall beaker, closed with a round-bottomed flask full of cold water. A few marble chips in the beaker serve to maintain freedom from acidity. Redistil the solvent at frequent intervals, *i.e.*, after about 15 to 20 panels have been degreased per litre of solvent. Remove the basket and allow the specimens to cool. Suspend them in the trichlorethylene vapour for 30 sec, remove, allow to cool, and repeat the vapour treatment twice. Once the specimens have been degreased, the rest of the procedure should follow without delay.

Stopping-Off

Dip the specimen in paraffin wax, maintained at 90° to 95° C, so that a margin approximately 5 mm wide is waxed-off on the two long edges and on one short edge, and a margin approximately 10 mm wide on the other short edge, referred to subsequently as the ' top ' of the specimen. This 10-mm margin should cover the identification marks. Allow the molten wax to cool to 70° to 75° C and then maintain it at this temperature. Repeat the dipping in order to build up a thick wax film over the cut edges. Wax the top first and allow to cool, when the specimen may be held at this place and the other edges dipped. If desired, the stopping-off may be carried out by varnishing with an air-drying nitrocellulose composition, though since complete covering of cut edges is difficult with such material, it would be desirable to apply a subsequent coating of paraffin wax to the extreme edges.

Testing

Warm all stock solutions to 20° C and measure 100 ml of the ammonium thiocyanate, 100 ml of the acetic acid, and 50 ml of the hydrogen peroxide into a 250-ml squat beaker. Stir well and immediately insert the prepared specimen so that it stands vertically. Proceed similarly with any other specimens it is desired to test at the same time, and finally make up 250 ml of test solution in a separate beaker, the contents of which are for use in estimating the iron dissolved in the tests.

Allow each test to proceed for 14 min 50 sec, stir the solution with the specimen for 10 sec, and then withdraw it. To each of the beakers, including the blank, add 2 ml of concentrated sulphuric acid, and stir well.

Estimation of Iron

The iron is estimated by comparing the red ferric thiocyanate colour in the test solutions with standards. The comparison may be effected with any of the usual instruments, such as the photo-electric absorptiometer, Dubosq colorimeter, etc. The following method, using Nessler cylinders, is described in detail, as such equipment is more likely to be found in works laboratories.

Pour 100 ml of the test solution and 100 ml of the unused solution into separate matched Nessler cylinders, cleaned with hydrochloric acid and water.

To the 'standard' cylinder add dilute ferric iron solution from a burette till the colour is nearly equal to that of the test solution when viewed vertically through the cylinders, using a white mat paper as a light reflector. Add sufficient distilled water to the test solution to make its volume equal to that of the standard. Stir the two solutions and complete the matching by adding iron solution drop by drop, till the colours are equal. Note the burette reading (t ml). The amount of iron in the test solution is then :

$$\text{Fe} = 0{\cdot}252t \text{ mg.}$$

If it is considered more convenient to add the 2 ml of concentrated sulphuric acid as a dilute solution in water, it is suggested that 5 ml of a 40% v/v solution be employed, when the conversion factor above will be 0·255.

Measure the area of the tinplate exposed on both sides of the specimen and calculate the amount of iron found in milligrammes per square decimetre of exposed plate.

REPRODUCIBILITY OF RESULTS OBTAINED BY THE RECOMMENDED PROCEDURE

To test the reproducibility of the results obtained by the foregoing procedure, a sheet of tinplate from an Abercarn machine (nominal tin coating 20 oz per basis box) was cut into 64 pieces, each 5·8 cm × 8·5 cm. These specimens were tested independently by four workers in the authors' laboratories. Each worker tested 16 specimens in groups of eight on each of two occasions, at least one day intervening between the testing of each group. The groups of eight were chosen on the basis of a random latin square. The results obtained were as follows :

First Test

Operator	Mean Porosity
(1)	0·44 ; 0·38
(2)	0·44 ; 0·31
(3)	0·33 ; 0·37
(4)	0·35 ; 0·41

Second Test (Different Operators, Different Tinplate)

Operator	Mean Porosity
(1)	0·13 ; 0·15
(2)	0·13 ; 0·14
(3)	0·13 ; 0·15
(4)	0·15 ; 0·17

A statistical examination of the individual results indicated that the test was reproducible as between the various workers and occasions, as follows :

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	Variance Ratio F
		First Test		
Rows	0·9516	7	...	...
Columns	0·1112	7	...	...
Operators	0·0295	7	0·0042	3·00
Residual	0·5296	42	0·0126	
		Second Test		
Rows	0·0840	7	...	...
Columns	0·0109	7	...	...
Operators	0·0113	7	0·0016	1·12
Residual	0·0744	42	0·0018	

The 5% and 1% points of F for 42 and 7 degrees of freedom are 3·34 and 5·91 respectively, and it is thus seen that differences of operator make no significant difference to the results obtained. Since operators working in one laboratory will, almost of necessity, use the same reagents and distilled water, it was thought desirable to carry out a similar test between two laboratories. The Tin Research Institute kindly consented to act as the second laboratory, and the test was carried out in the same manner as those previously described, except that one operator at each laboratory tested four batches. The mean porosities of batches of eight specimens were :

Tin Research Institute	British Iron and Steel Research Association
0·12	0·14
0·14	0·14
0·19	0·15
0·15	0·17

The statistical analysis was as follows :

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	Variance Ratio F
Rows ...	0·320	7	...	...
Columns	0·027	7	...	...
Occasions	0·023	7	0·0033	2·75
Residual	0·050	42	0·0012	

The 5% and 1% points of F for 7 and 42 degrees of freedom are 2·25 and 3·12 respectively. It is seen that the degree of reproducibility is not as good as previously, but it may still be considered adequate. Attempts to assess the reproducibility of the test on a larger scale, involving four laboratories and samples taken from a batch of tinplates, were unsuccessful. Although there was agreement between some of the laboratories and between different occasions in individual laboratories, complete reproducibility as between laboratories and occasions was not found. Areas of very high porosity are known to occur haphazardly on tinplates, but there are usually insufficient of them to ensure that batches containing a relatively small number of specimens will include an equal number of these very porous areas. Sampling difficulties, therefore, make it extremely difficult to confirm reproducibility on a large scale, unless a great many specimens are tested.

RELATIVE POROSITIES OF TINPLATE SHEETS

Whilst it is essential that the test should be reproducible, *i.e.*, the results obtained by any one worker should be reproduced, within experimental error, by any other operator with a statistically equivalent sample, it is equally essential that the results obtained on different grades of tinplates should bear the same relationship to each other as do the porosities of the different plates.

The thiocyanate test affords an indication of the total area of the discontinuities in a tin coating and, unfortunately, there is no method for determining absolutely this total area. It is known, however, that porosity as measured *by the number of pores per unit area is dependent upon the thickness of the tin coating.* By analysis of results obtained by Hoare,[4] Taggart has shown[4] (*loc. cit.*, p. 123P) that porosity is related to coating weight by the following equation :

$$\text{Log}_{10}P = 3{\cdot}653 - 2{\cdot}785 \log_{10}W \pm 0{\cdot}505 \ldots\ldots (1)$$

where P is the number of pores per 100 sq.cm., W is the thickness of the tin coating expressed in ounces per basis box, and the last term indicates the limits between which 95% of the results are found to lie.

A similar type of equation would be expected to hold for the relationship between coating weight and porosity as measured by the thiocyanate test, if the

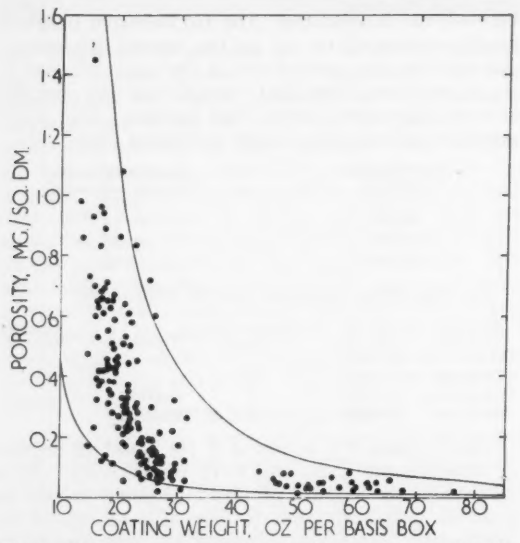

Fig. 1—Porosity of hot-dipped tin coatings. Limits from $\log_{10}P' = 2{\cdot}39 - 2{\cdot}22 \log_{10}W \pm 0{\cdot}52$

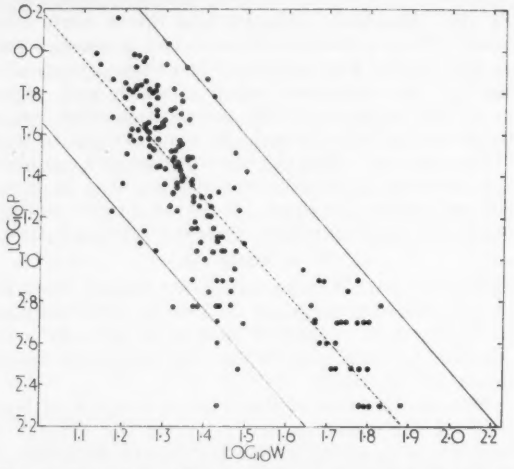

Fig. 2—Porosity of hot-dipped tin coatings. Line of best fit (by method of least squares): $\text{Log}_{10}P' = 2{\cdot}39 - 2{\cdot}22 \log_{10}W$

conditions stated above were realized. To verify this, a large number of small samples taken from sheets carrying tin coatings varying from 15 to 75 oz per basis box, coated in single- and double-sweep pots and by hand, were examined for porosity and for coating weight. In order to eliminate any levelling influence of treating both sides of the samples together, the two faces of each specimen were examined separately (by varnishing them alternately with a nitrocellulose composition), and considered as two samples. In this way the porosities of samples of precisely known coating weight were obtained.

The series of pairs of values so obtained are shown plotted in Fig. 1, and logarithmically in Fig. 2. The results are best represented by the equation:

$$\text{Log}_{10}P' = 2{\cdot}39 - 2{\cdot}22 \log_{10}W \pm 0{\cdot}52 \quad \ldots\ldots(2)$$

where P' is the porosity in milligrammes of iron dissolved per 100 sq.cm. of surface, W is the coating weight in ounces per basis box, and the last term has the same significance as in equation (1).

It will be seen that the two equations are of the same form; the difference in constants is presumably ascribable to the fact that the properties measured are not completely interchangeable. Equation (2) indicates that the results obtained by the thiocyanate test, as modified, are an essentially true measure of the relative porosities of different materials.

Equation (2) has a value apart from that of checking the thiocyanate method. Since it was obtained with samples representative of good present-day commercial hot-dipped material, and many subsequent porosity estimations have confirmed its validity, it serves as a comparison criterion; *e.g.* if the porosity of a tinplate made by, say, some electrolytic process or by a modification of an existing hot-tinning unit, were found to be higher or lower than the limits predicted from its coating weight, the material could be classed as being of inferior or superior quality. This relationship is of value in so far as it provides a guide as to whether modifications to the tinning process have resulted in a reduction of porosity as compared with standard industrial practice. It should be noted that equation (2) was obtained from measurements on tinplate carrying 15 oz or more of tin per basis box; any extrapolation in the direction of lighter coating weights should be treated with reserve, since the relationship may not then hold.

CONCLUSION

It has been shown that the thiocyanate porosity test originally proposed by Kerr is liable to give inaccurate results unless care is taken in the cleaning of the specimens, in the making of the testing solutions, and in the estimation of the amount of iron dissolved. Suitable modifications and precautions have been described. The modified method has been shown to be sufficiently reproducible to serve as a reliable method for assessing the porosity of tinplates. The results obtained, when used in conjunction with an equation given in the text, may be of value in assessing the beneficial or detrimental effects of any modifications of existing processes or of new methods of producing tinplate.

Acknowledgments

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Resistance Strain Gauges for the Measurement of Roll Force, Torque, and Strip Tension

By J. Rankine, B.Sc., M.I.Mech.E., D.I.C., W. H. Bailey, B.Sc.(Eng.), and F. P. Stanton, A.M.I.Mech.E.

SYNOPSIS

The methods of measuring roll separating force, spindle torque and strip tension in the 10 in. × 10 in. two-high experimental cold-rolling mill at Sheffield University by the use of resistance strain gauges are described and illustrated. The tension meter consists of a combination of a torque meter and a device which automatically divides the value of the torque by the coil radius. The equipment operates on direct current at 100 V. which can be supplied from dry batteries. Electronic equipment is limited to one single-valve D.C. amplifier which is used only when measuring very low tensions. The values of torque and tension are indicated on 2½-in. pointer meters, the readings of these and similar meters indicating other variables being recorded simultaneously by a 35-mm. cinematograph camera equipment.

Introduction

THE experimental cold rolling mill, which has been equipped with the roll-free torque and tension measuring instruments described below, is situated in the Applied Science Department of Sheffield University. It is a 10 in. × 10 in. two-high mill, and has coiling and uncoiling reels designed to provide the strip with forward and backward tension loads of from nearly zero to more than two tons. The peripheral speed of the rolls is infinitely variable up to a maximum of 307 ft./min. and the maximum horse-powers of the main-mill, wind-reel, and drag-reel motors are 120, 40, and 40 respectively. The roll-force meters are designed for loads up to 50 tons per screw. Section III of The First Report of the Rolling Mill Research Sub-Committee of the Iron and Steel Industrial Research Council* gives a full description of this mill, and in this and the following section can be found particulars of the arrangements in operation at the end of 1945 for the measurement of roll force, spindle torque, and strip tension.

The roll-force and torque meters then in use were based upon the conversion of strain displacements into change of inductance and change of capacitance respectively. These produced, in tuned A.C. bridge circuits, proportional out-of-balance currents which were amplified and applied to graphic recorders, and to 2½-in. pointer-type meters for visual and photographic observation. Further electronic equipment consisted of a 20-kilocycle oscillator to supply the bridges. It will be seen that the substitution of the present D.C. resistance strain-gauge equipment has resulted in simplification. In the present application, where cinephotography of pointer meters is employed, the inability to use graphic recorders with the simpler system has proved no disadvantage.

In the mechanical design of the wind and drag coilers no provision was made for the measurement of tension, because the basic design of the electrical equipment was such that it was expected that the measure of the armature currents would also be the measure of the tensions, and it was hoped that it would be possible to mark the tension-setting control-wheel dials in terms of tension. When these possibilities were investigated, it was found that the tension for a given armature current varied with the size of coil and the speed of rolling. A series of tests was then made to determine the mechanical and electrical losses for all combinations of variables, and from these it was possible to calculate the tension from readings taken during rolling, but it was not possible to estimate before a pass the armature current which would give the tension required, as this was influenced by the forward slip, which could not be predicted.

The possibility of contriving a direct-reading tension meter was therefore examined. It was found possible for a torque meter of the resistance strain-gauge type to be arranged between the reduction gear and the coil drum. In addition to this, a device has been fitted which automatically divides the torque measurement by the coil radius, so that tension and not torque is shown on the indicating instruments, two of which are provided for each coiler. One of these is mounted on the main instrument panel, and the other on the tension-control cabinet so that it can be kept under constant observation by the tension-setting operator.

The indicating meters for all instruments were originally mounted on a panel fixed to the wall close to the mill, and the cinematograph camera and lights were mounted on independent portable stands. Subsequently the camera was carried on a post which, when required, was placed in a socket in the floor, and the lights were carried on a frame supported by ropes which passed over pulleys in the roof and which were attached to counterweights. The present arrangement, which is described later in this paper, was substituted primarily to eliminate obstruction of

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Mr. Rankine is Development Engineer with the Whitehead Iron and Steel Co., Ltd.

Mr. Stanton is engaged on rolling-mill research with the British Iron and Steel Research Association.

* *The Iron and Steel Institute*, 1946, *Special Report No.* 34, pp. 69–96.

the working space round the mill, but the opportunity was also taken to make other improvements.

ROLL-FORCE METERS (LOAD METERS)

The load-carrying element employed in the inductance-type roll-force measuring equipment, which is still available as an alternative to the resistance-gauge equipment, consists of a steel cylinder placed, with axis vertical, between screw and chock, and the elastic compression of the cylinder is a measure of the roll force. The compression, which is about 0·0014 in. for 50 tons in this case, is made to vary

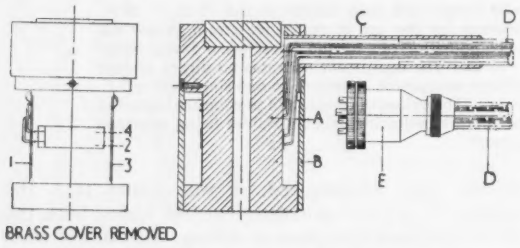

Fig. 1—Resistance strain-gauge load meter

the air gap in an inductive unit mounted inside the steel cylinder. The cylinders and the electrical arrangements, by which the change in inductance resulting from the change in air gap is converted into deflection of pointer meters, are described in Section IV of the Report.*

The resistive-type meters employ strain gauges made by the British Thermostat Co., Ltd. Each consists of a coil of 0·001-in. dia. wire wrapped round a flat paper former which is approximately 1 in. × 0·25 in. × 0·005 in. This coil is sandwiched between two pieces of paper 1·5 in. × 0·5 in., and the whole is impregnated with a thermo-setting synthetic resin. The ends of the coil are spot welded to flat-tail leads, about 1 in. long, to which the external leads can be soldered. The gauge is glued by means of an acetone-soluble cellulose cement to the surface in which the strain is to be measured, and, after thoroughly drying (one week at room temperature, less if heated) it is covered with an insulating varnish to prevent moisture from causing corrosion of the coil or deterioration of the cement.

* *The Iron and Steel Institute*, 1946, *Special Report No.* 34, pp. 97–123.

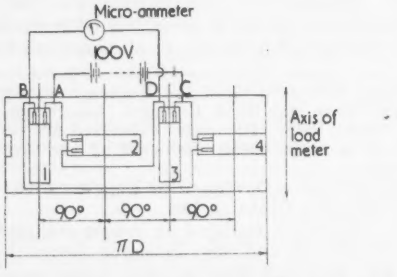

Fig. 2—Load meter. Disposition of strain gauges

Table I

Strain e along Axis of Gauge	Axial Load, W tons	Bending,† M tons.in.	Torque, T tons.in.
No. 1	$-f_a/E$*	$-f_b/E$*	...
No. 2	$+f_a/mE$	...	...
No. 3	$-f_a/E$	$+f_b/E$	...
No. 4	$+f_a/mE$	...	...

*** Axial stress $f_a = 4W/\pi(D^2-d^2)$, and bending stress, $f_b = 32DM/\pi(D^4-d^4)$, where D is the outside dia. of a hollow cylinder (in.), d is the inside dia. (in.), E is Young's Modulus (tons/sq. in.) and $1/m$ is Poisson's Ratio.**

† To simplify analysis, the bending is assumed to be in the plane containing the axes of gauges 1 and 3, and the width of the gauges is neglected.

Extension of the surface is transmitted to the fine-wire coil, the resistance of which is increased in direct proportion to the strain, principally on account of the increase in length and decrease in cross-sectional area of the wire, but there is also some change in specific resistance. Compression causes a corresponding decrease in resistance.

Figure 1 is a drawing of a load meter in which the principal member, A, is made of high-tensile steel† and is inserted in place of the normal breaker between the screw and the chock. Resistance strain gauges 1, 2, 3, and 4 are glued to the centre portion and are protected by the brass sleeve B. The disposition of them is shown more clearly in Fig. 2, which is a developed view of the surface of the cylinder. The leads from the gauges are brought out through the brass tube C, and flexible conduit D, to the four-pin plug E. Sockets to receive this plug are provided on

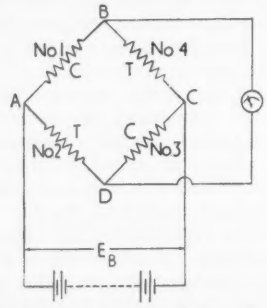

Fig. 3—Load meter. Strain-gauge bridge

the mill housing and adjacent to the 50-ton testing machine in which calibration is carried out. It will be apparent that the effect of the roll separating force will be to compress the cylinder axially and to cause a lateral dilation. Gauges 1 and 3, which are placed axially, will therefore be subjected to compressive stress and their resistances will decrease, while the resistances of gauges 2 and 4, being placed circumferentially and therefore receiving some tensile strain, will increase.

† British Standard Specification, No. S65.

The values of these strains for a cylinder D-in. dia. with an axial hole having a diameter of d in., and of those which occur if the device is accidentally subjected to bending or torsion, are shown in Table I.

The gauges are connected, as shown in Fig. 3, to form a Wheatstone bridge which is adjusted to be in balance under the condition of no load between screw and chock.

The relationship between the load applied and the micro-ammeter reading can be derived as follows :

E_B = input voltage
R_G = unstrained gauge resistance, ohms
δR = change in resistance of gauge due to strain, ohms
E_{AB} = voltage drop from A to B with meter removed
E_{AD} = voltage drop from A to D with meter removed
E_{BD} = voltage across BD with meter removed
R_N = network resistance across BD with meter removed, ohms
R_M = output meter resistance, ohms
I_M = meter current, micro-amps.
S = gauge factor.

The resistance change δR is connected with the strain e by the following expression :

$$S = \delta R/R_G e \text{ or } \delta R = R_G eS$$

Therefore the resistance of the gauge, when under strain e, is :

$$R_G + \delta R = R_G + R_G eS = R_G(1 + eS)$$

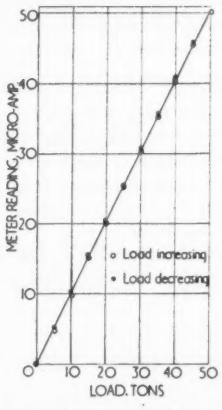

Fig. 4—No. 1 load-meter calibration, 13th February, 1948. 50·3 micro-amps. represented 50 tons. A check on 10th March, 1948 gave a linear relationship with a reading of 51·0 at the maximum load of 50 tons. After this calibration run the maximum load was applied for 15 min. and the meter reading changed from 51·2 to 51·0

The gauge factor S is constant for a given type of gauge and is 2·15 for the 2500-ohm British Thermostat Co., gauge which is used in these load meters.

Therefore, with an axial stress of f_a upon the cylinder, the resistances in the arm of the bridge formed by gauges 1, 2, 3, and 4 will be as follows :

Gauge No. 1 : $R_G(1 - f_a/E.S)$
„ No. 2 : $R_G(1 + f_a/mE.S)$
„ No. 3 : $R_G(1 - f_a/E.S)$
„ No. 4 : $R_G(1 + f_a/mE.S)$

If removal of the meters is assumed, the potential differences will be as follows :

$$E_{AB} = E_B \times \frac{R_G(1 - f_a/E.S)}{R_G(1 - f_a/E.S) + R_G(1 + f_a/mE.S)}$$

$$E_{AD} = E_B \times \frac{R_G(1 + f_a/mE.S)}{R_G(1 + f_a/mE.S) + R_G(1 - f_a/E.S)}$$

therefore $E_{BD} = E_{AD} - E_{AB} =$

$$E_B \times \frac{(1 + f_a/mE.S) - (1 - f_a/E.S)}{(1 + f_a/mE.S) + (1 - f_a/E.S)}$$

$$= E_B \times \frac{f_a/mE.S + f_a/E.S}{2 + f_a/mE.S - f_a/E.S}$$

$$= \frac{E_B f_a S(1 + 1/m)}{E[2 - f_a S/E(1 - 1/m)]}$$

$$= \frac{E_B f_a S(1 + 1/m)}{2E - f_a S(1 - 1/m)}$$

The current through the meter, when it is reconnected, is by Thevenin's Theorem :

$$I_M = \frac{E_{BD}}{R_N + R_M}$$

$$R_N = \tfrac{1}{2}[R_G(1 + f_a/mE.S) + R_G(1 - f_a/E.S)]$$
$$= R_G/2(2 + f_a/mE.S - f_a/E.S)$$
$$= R_G/2E[2E - f_a S(1 - 1/m)]$$

therefore $I_M = \dfrac{E_B f_a.S(1 + 1/m)}{2E - f_a.S(1 - 1/m)} \times \dfrac{1}{R_G/2E[2E - f_a.S(1 - 1/m)] + R_M}$

$f_a.S(1 - 1/m)$ is very small in comparison with $2E$ and can therefore be neglected, in which case :

$$I_M = \frac{E_B f_a.S(1 + 1/m)}{2E(R_G + R_M)} \times 10^6 \text{ micro-amps.}$$

Substituting $\dfrac{4W}{\pi(D^2 - d^2)}$ for f_a

$$I_M = W \times \frac{2(1 + 1/m)E_B.S}{\pi(D^2 - d^2)E(R_G + R_M)} \times 10^6.$$

In this case $D = 2$ in., $d = 0{\cdot}438$ in., $E_B = 100$ V., $S = 2{\cdot}15$, and $R_M = 1000$ ohms. If m is assumed to be 4, and E to be 12,500 :

$$W = 0{\cdot}97 I_M$$

The sensitivity of this equipment to bending can be derived in a similar manner ; it will be found to be extremely small, and, in fact, it can be said that these meters do not respond to bending.

Calibration of Load Meters and Results Obtained

The load meters are calibrated in a 50-ton Avery self-indicating universal testing machine. This is a machine in which the straining is carried out by means of a hydraulic ram, and the load is determined by measurement of the hydraulic pressure, using a proportional ram operating upon a pendulum.

The results derived from a typical calibration sheet are plotted in Fig. 4, with which is given the change in reading which occurs after a period at full load, and the difference in calibration after an interval of about a month. The accuracy with which load can be measured, including errors in the load meters, in photographing, and in reading the projected film, is estimated to be $\pm 2\%$ for readings greater than one quarter of the full-scale reading.

Torque Meters

The torque in the universal spindles, through which the drive is taken to the rolls, was first assessed by measuring the twist over a gauge length of 8 in.

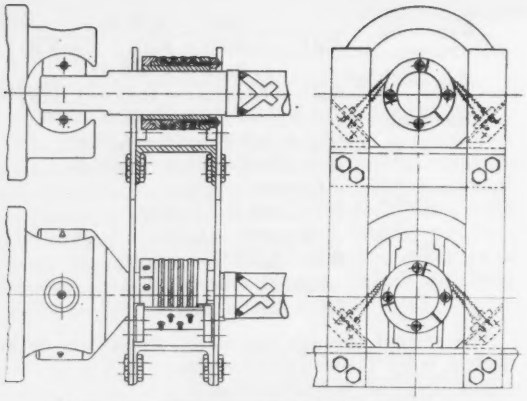

Fig. 5—Torque meters on mill spindles

Each torque meter consisted of a pair of insulated aluminium plates, $6\frac{1}{4}$ in. long × $2\frac{1}{4}$ in. wide, placed approximately 0·1 in. apart to form an air-dielectric condenser, the plane of the dielectric being radial and parallel to the spindle axis. Each plate was supported by an arm attached to the spindle, the distance between the arms being 8 in. Twisting of the spindle caused the distance between the plates to change from the unloaded distance of 0·1 in., with a corresponding change in capacitance and the production of an out-of-balance current in a bridge circuit of which the condenser formed a part, connection being made between the stationary and revolving components by means of slip-rings and brushes. The out-of-balance current was amplified and applied to an indicating meter and a recorder, as in the case of the inductance roll-force meters. Useful results were obtained with these meters, but they were found to lack robustness. There was some cyclic variation in reading which was thought to be spurious and may have been due to bending, against the effect of which it was not certain that this design was proof. For these reasons, and to obtain the simplification to which reference has been made, it was decided to use resistance strain gauges arranged so that they were not responsive to bending.

The present torque meters are illustrated in Fig. 5, which is considered to be self-explanatory. The strain gauges are placed at 45° to the spindle axis, as this is the direction in which normal strains are at a maximum. Figure 6 is a developed view of the relevant portion of the spindle with the gauges in position, and Table II gives the strains to which they will be subjected with the spindle under torsional, bending, and axial loading.

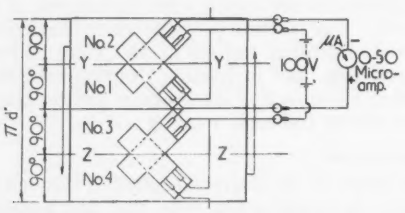

Fig. 6—Torque meters. Disposition of strain gauges

Table II

Strain e along Axis of Gauge	Torque, T tons.in.	Bending,† M tons.in.	Axial Load, W tons
No. 1	$+fs/2G$ *	$+f_b/E$ *	$+f_a/E$ *
No. 2	$-fs/2G$	$+f_b/E$	$+f_a/E$
No. 3	$+fs/2G$	$-f_b/E$	$+f_a/E$
No. 4	$-fs/2G$	$-f_b/E$	$+f_a/E$

* Shear stress, $fs = 16T/\pi D^3$, bending stress, $f_b = \frac{32M}{\pi D^3}$ $\cos^2 45°$, and axial stress, $f_a = \frac{4W}{\pi D^2}\cos^2 45°$, where D is the solid-spindle dia. (in.), E is Young's Modulus (tons/sq. in.), and G is the Rigidity Modulus (tons/sq. in.)

† To simplify analysis, the bending is assumed to be in a plane containing $YY + ZZ$ (as on shaft), and change of y is neglected ; *i.e.*, a shaft large in comparison with the gauge length is assumed.

If the resistance changes for the gauges in the bridge are worked out, as has been done for the load meters, the balance will be found to be undisturbed by the application of axial or bending loads.

The expression for torque will be :

$$I_M = T \times \frac{8E_BS}{\pi L^3 G(R_M + R_G)}$$

For the present spindles $G = 5150$, and $D = 2{\cdot}25$ in. ; $E_B = 100$ V., and $R_M = 1000$ ohms,

therefore $T = 0{\cdot}374 I_M$

Calibration of Torque Meters and Results Obtained

For designing the meters the above calculation was carried out, but the relationships between T and I_M used in the computation of rolling results are obtained experimentally. Arms having an effective length of 6 ft. are attached to the outer ends of the rolls, and weights are hung from them. The results derived from a typical calibration sheet are plotted in Fig. 7, with which is given the change in reading which

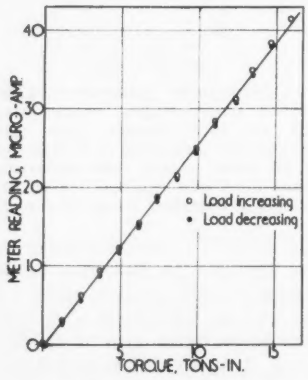

Fig. 7—Lower-spindle torque-meter calibration, 9th October, 1947. After the calibration run the maximum torque of 17·2 tons.in. was applied for 20 min. and the meter reading changed from 45·7 to 45·3. A check calibration on 8th December, 1947 gave a linear relationship with a reading of 47·0 at the maximum torque of 17·2 tons.in.

occurs after a period at full torque, and the difference in calibration after an interval of two months. The overall accuracy of the torque meters is similar to that of the load meters.

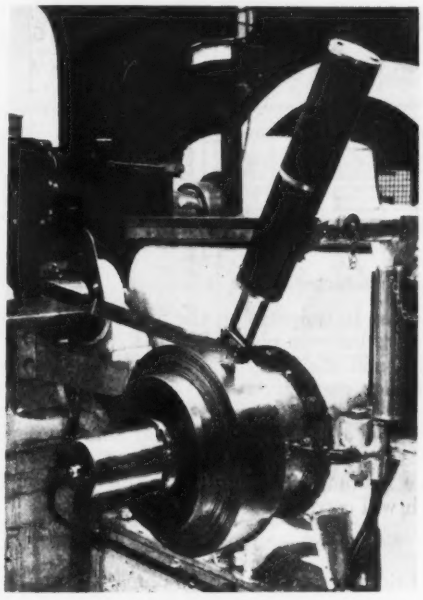

Fig. 8—Tension meter in operation showing radius-factor device in position. This is pivoted on the support at the right of the photograph so that it may be swung out of the way for removal of coil

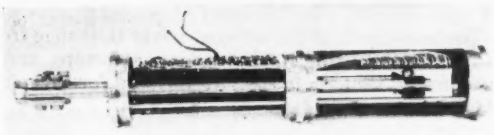

Fig. 9—Radius-factor device. Covers removed

TENSION METERS

The mechanical arrangement of the tension meters is shown in Figs. 8 to 11. Referring to Fig. 10, the output spindle *A* of the gearbox originally drove the coiler drum through a plain key in the key-way *B*. This key has been removed, and an extension shaft *C* has been dowelled and bolted to the outer end of the spindle. A sleeve *D* has been bolted to the drum, and is connected at its outer end to the extension shaft *C*. The drive is thus transmitted to the drum through the shaft and the sleeve. A strain-gauge bridge, similar in every respect to that described for the mill-spindle torque meters, is glued to the plain portion of shaft *C*. Leads from the gauges pass through the hollow dowel *E* and along the disused key-way to the slip-rings *F*. From the wires *G*, which embrace the slip-rings, leads are taken to the supply battery *via* the radius factor device, and to the meters on the instrument panel and tension control cabinet. The supply voltage is 100, as for the torque meters, and the output for 4000-lb. tension is 48 micro-amps.

If any friction occurs between the spindle *A* and the coiler drum some of the driving torque will be taken at this contact, and the shaft *C* will not transmit the full torque. When using a plain cast-iron drum with a clearance of 0·030 in. between it and the spindle (this clearance is necessary to prevent binding of the drum when coils wound under tension cause it to contract), it is found that insignificant errors occur for tensions exceeding 1000 lb. In order to secure the highest accuracy at lower tensions, a drum has been constructed in which there is a ball bearing between the spindle and the drum. This is the one shown in the figures. Tensions down to 50 lb. can be measured with the ball-bearing drum. The output of the meter is very low at this tension, and a one-valve D.C. amplifier, having a gain of about 4, is used to increase the output when investigating the effect of very low tensions.

As stated earlier, the device measures the torque on the coiler shaft, and in order to obtain a direct indication of the tension applied to the strip, correction must be made for the fact that the radius of the coil changes progressively as the strip is coiled and un-

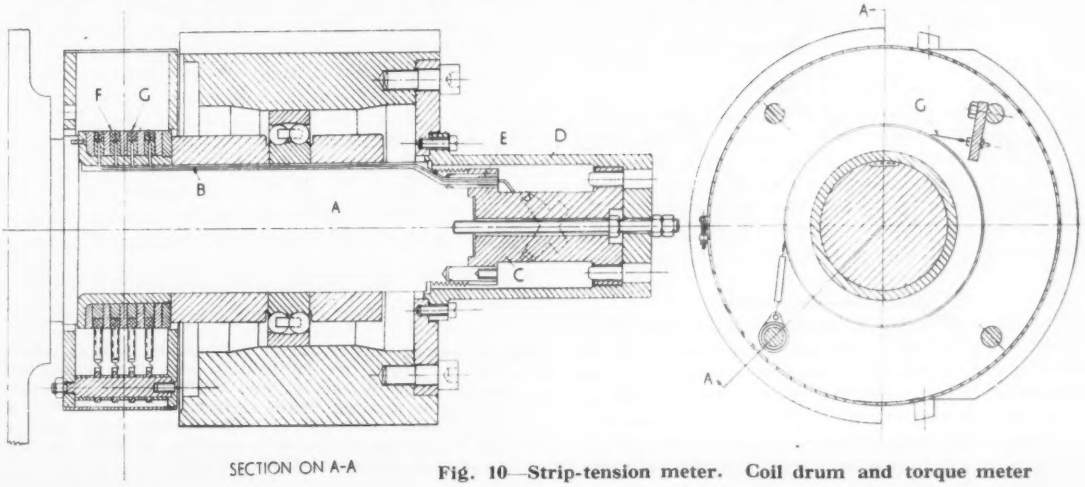

Fig. 10—Strip-tension meter. Coil drum and torque meter

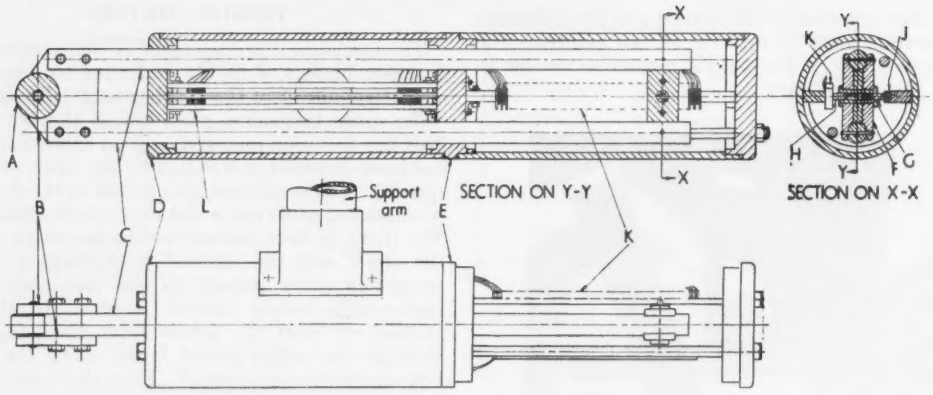

Fig. 11—Strip-tension meter. Radius-factor device

coiled. The radius-factor device, which is illustrated in Figs. 9 and 11, allows the correction to be made automatically. Its construction and operation are as follows :

It is fundamental that, for a given shaft and gauge combination, the output of the bridge is proportional to the torque and to the applied voltage, *i.e.* :

$I_M = kE_BT = kE_BPr$ for the tension meter,
P = strip tension, and r = coil radius.

It is evident, therefore, that I_M will be proportional to P if E_Br is made constant ; that is, if E_B is made equal to a constant $(k_1) \times 1/r$. E_B is made proportional to $1/r$ by means of the radius-factor device (shown with the covers removed in Fig. 9) connected in series with the bridge, as shown in Fig. 2. Referring to the diagram, Fig. 11, a wheel A, which runs on the strip, is carried on a spindle between plates B, rigidly connected to the rods C, which pass through the holes in plates D and E, in which they are a sliding fit. Attached to these rods is the component F, built up of bakelite board and carrying the spring-loaded plungers G and H. Plunger G runs on a continuous brass bar J, and plunger H over a series of contacts forming the track K. These contacts are connected to tappings on the resistance L, housed in the space between plates D and E. Leads are taken from J and the lower end of K to the battery and the bridge respectively. It will be seen, therefore, that the voltage applied to the bridge is reduced below that of the battery by an amount depending upon the position of H.

The maximum value of E_B has been made 100 V., which will correspond to a radius of 5 in.

Therefore, $100 = k_1/5$, or $k_1 = 500$

The bridge resistance is 2500 ohms. Therefore, if for any radius r, the resistance between H and A (Fig. 12) is R_5 ohms :

$E_B = 100 \times 2500/(2500 + R_5) = 500/r$
therefore $(2500 + R_5)/2500 = r/5$
therefore $(2500 + R_5)/500 = r$
therefore $2500 + R_5 = 500r$
therefore $R_5 = 500r - 2500$

The movement of the slider to cover the range from $r = 5$ in. to $r = 10$ in. is divided into 100 steps, and it will be seen that the resistance increase for each step is 25 ohms.

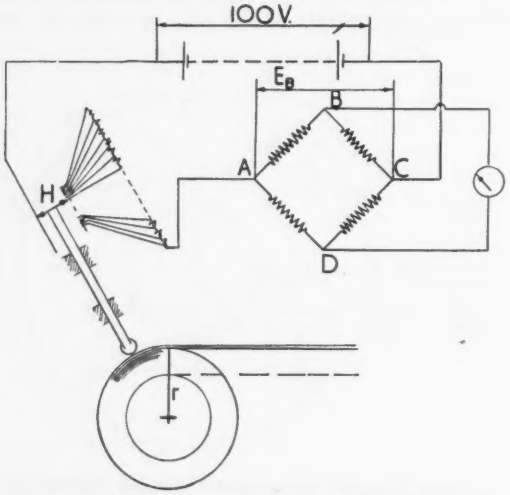

Fig. 12—Strip-tension meter. Circuit diagram

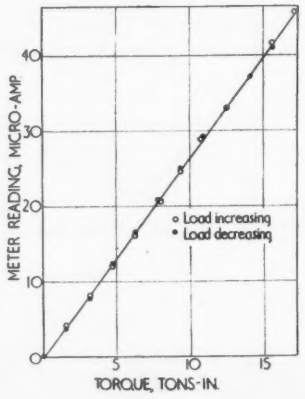

Fig. 13—Drag-tension meter calibration, 31st October, 1947. After the calibration run the maximum torque of 15·96 tons.in. was applied for 15 min. and the meter reading changed from 41·8 to 40·9. A check calibration on 11th December, 1947 gave a linear relationship with a reading of 42·8 at the maximum torque of 15·96 tons.in.

Table III

PROVING TEST OF RADIUS-FACTOR DEVICE

Radius, in. (r)	Theoretical Output, micro-amp. ($250/r$)	Actual Output, micro-amp.		Percentage Error	
		Radius Increase	Radius Decrease	Radius Increase	Radius Decrease
5·0	50·0	50·0	49·9	0·0	−0·2
5·5	45·5	45·8	45·6	+0·7	+0·2
6·0	41·7	41·8	41·7	+0·2	0·0
6·5	38·5	38·7	38·5	+0·5	0·0
7·0	35·7	35·8	35·7	+0·3	0·0
7·5	33·4	33·4	33·4	0·0	0·0
8·0	31·2	31·2	31·1	0·0	−0·3
8·5	29·4	29·4	29·4	0·0	0·0
9·0	27·8	27·7	27·7	−0·4	−0·4
9·5	26·3	26·2	26·2	−0·4	−0·4
10·0	25·0	24·9	...	−0·4	...

Calibration of Tension Meters and Results Obtained

The tension meters are calibrated by attaching an arm to the drum which is fitted with a ball bearing, and hanging weights on the end of the arm. Typical results are plotted in Fig. 13, below which are given figures for drift and a repeat calibration. A rapid check of the meters can also be carried out by wrapping a wire rope round the drum and passing it over a pulley in the roof, a weight being attached to the free end of the rope. There is some advantage in this second method because the drum is revolved for one or two revolutions under load, but the maximum tension which can be applied is 1000 lb. This is only one quarter of the nominal maximum tension, but it has been found that if the meters read correctly for 1000-lb. load applied by this method, they are correct for higher loads such as can be applied with the arm.

A check on the accuracy of the radius-factor device has been made by shunting one of the strain gauges to give a reading on the tension-indicating meter of 50 micro-amps. when the follower was resting on the drum (5-in. radius). A series of distance pieces, increasing from $\frac{1}{2}$ in. to 5 in. in $\frac{1}{2}$-in. steps, was then inserted between the follower and the drum, and the meter readings taken for each piece. The values of these, with the values theoretically required and the discrepancies, are shown in Table III.

Although the nominal maximum tension which the coilers can apply is 4000 lb., or a little higher, it has been found that tensions up to 8000 lb. can be applied without damage to the mill or the tension meters at the lower mill speeds. No attempt has been made to apply these higher tensions at high mill speeds.

PHOTOGRAPHIC RECORDING OF READINGS

Figure 14 is a photograph of the present arrangement of meter panel and camera which are used for recording the readings of roll force, torque, tension, and other variables. In addition to a clock with centre-sweep seconds hand, which provides a time base, spaces are provided in the panel for twenty-nine $2\frac{1}{2}$-in. Weston meters. The size of the panel is 17 in. × 14 in. and the increase in the number of meters from twelve in the original panel (17 in. × 13 in.) was obtained by turning off the meter flanges and supporting them from the back.

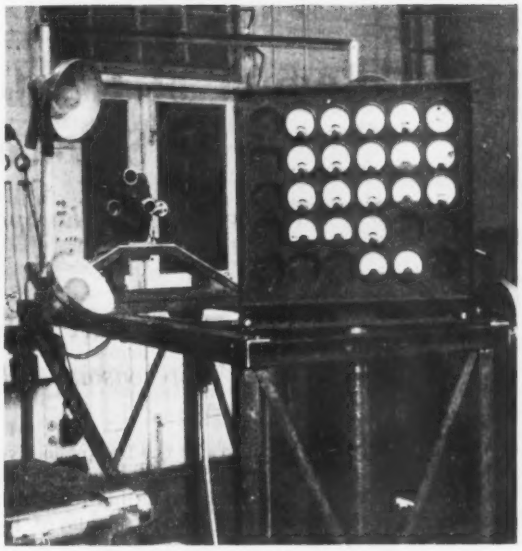

Fig. 14—Instrument panel turned for visual reading

The panel, floodlights, and camera are mounted on a stand built up of structural-steel sections. It is portable, with all leads brought to it in a flexible armoured cable, and, to avoid distortion when on an uneven floor, rests on the ground at three points only. The lights are switched on by a contactor, controlled by a press button which also controls the camera-release solenoid. Three such press buttons are provided, enabling operation to be carried out from the camera stand itself, the tension control cabinet, or the ingoing side of the mill. The camera is a 35-mm. Bell Howell instrument driven by clockwork, and provision is made for its precise location and focus at either of two distances from the panel. This last provision, together with the way in which the meters are grouped, enables larger images to be obtained of the fewer numbers of meters used when rolling without tension.

CONCLUSIONS

The use of equipment employing resistance strain gauges for the measurement of roll separating force, torque, and strip tension has proved very satisfactory in this experimental mill, and it should be possible to employ similar equipment in many commercial mills. It is simple and inexpensive when indication, not recording, of the quantities measured is sufficient.

Acknowledgments

The authors wish to thank the Rolling Committee of the British Iron and Steel Research Association for permission to publish this paper. They also wish to thank those of their colleagues in the Rolling Mill Laboratory of B.I.S.R.A. who have helped in the design and installation of the equipment and in the preparation of this paper.

First Report of the Gases and Non-Metallics Sub-Committee

By W. W. Stevenson, G. E. Speight, R. M. Cook, and T. Rooney

Part I—Introduction

By W. W. Stevenson, F.R.I.C., F.I.M., A.M.I. Chem.E.

ALTHOUGH this report appears as the first collective publication from a comparatively new body, it is considered fitting that co-ordination with previous work on the subject shall be achieved by reference to the Oxygen Sub-Committee out of which the present Gases and Non-Metallics Sub-Committee arose.

The Oxygen Sub-Committee was formed rather more than twelve years ago and the first of its four reports was published in 1937. Methods for the determination of oxygen in steel had not received much attention in this country up to that time, and the primary function of the Oxygen Sub-Committee was to examine in detail and to develop the best methods available for the determination of oxygen in steel. At a later stage close attention was paid to methods for hydrogen and nitrogen and, in addition to steel, various types of iron were also investigated. By the time that the Fourth Report of the Oxygen Sub-Committee* appeared, towards the end of 1943, the primary purpose of the Sub-Committee in the perfection of methods for the determination of gases in iron and steel had been largely accomplished. The immense amount of work done by the co-operating members in the eight years of the life of the Oxygen Sub-Committee will be a permanent tribute to the memory of the late Dr. T. Swinden, who had so ably sponsored the work from its inception until his untimely death in 1944.

In addition to the loss of Dr. Swinden, many other changes in the constitution of the Oxygen Sub-Committee have taken place in the past four years, during which time the war has been brought to a victorious conclusion, and the whole structure of the scientific committees of the iron and steel industry has been reorganized under the aegis of the British Iron and Steel Research Association. Following the completion of its original task in the perfecting of methods, the Sub-Committee was reconstituted with the object of applying those methods to further knowledge of the origin and constitution of non-metallic inclusions and gases in iron and steel.

The broad function of the Gases and Non-Metallics Sub-Committee, of which body this is the First Report, was " to investigate the production of better quality steel from the standpoint of gaseous and non-metallic inclusions. This to include methods of determination and identification of these inclusions and studies of the processes by which they are formed." These broad terms of reference involved the co-option of specialists experienced in other branches of iron and steel research, additional to those expert chemists and physicists formerly associated with the work on methods of determination. In order further to expedite the work of the Sub-Committee, two study groups were formed to work respectively on gases and non-metallics in liquid steel and in solid steel. The Liquid Steel Study Group, under the able chairmanship of Mr. G. E. Speight, of The United Steel Companies, Limited, has been aiming " to develop and apply very rapid analytical methods for use on the furnace stage." The Solid Steel Study Group, under the active leadership of Mr. T. E. Rooney, of the National Physical Laboratory, has been aiming " to correlate the results of microscopical examination with those obtained by analytical methods, X-ray examination, etc., and to deal with problems relating to the identification of inclusions by microscopical methods in the various steels or other samples before the Sub-Committee." Both these study groups have made considerable progress in the past two and a half years in the respective directions in which they are working.

Changes in personnel of the Sub-Committee have been mentioned previously, and it is recorded with regret that the deaths of Mr. C. S. Graham (Messrs. John Lysaght, Ltd.) and of Dr. A. H. Jay (The United Steel Companies, Ltd.) have deprived us of their valuable services. Movements both inside and outside the industry have also resulted in the departure of other valued members. For example, Professor R. J. Sarjant felt compelled to resign his membership on accepting the Chair of Fuel Technology at Sheffield University, whilst Dr. W. C. Newell ceased to be an active member of the Sub-Committee on his appointment as Superintendent of the Steel Castings Division of the British Iron and Steel Research Association.

Mr. Stevenson is Chairman of the Gases and Non-Metallics Sub-Committee.

*Fourth Report of the Oxygen Sub-Committee, *Journal of The Iron and Steel Institute*, 1943, No. II, p. 231P.

The present constitution of the Sub-Committee and the Study Groups is as follows :

Gases and Non-Metallics Sub-Committee

Mr. W. W. STEVENSON (*Chairman*)	Messrs. Dorman, Long and Co., Ltd.
Mr. T. H. ARNOLD	Messrs. Hadfields, Ltd.
Mr. S. W. CRAVEN	I.C.I. (Alkali), Ltd., Northwich
Mr. I. M. MACKENZIE	Messrs. Colvilles, Ltd.
Dr. W. R. MADDOCKS	Sheffield University
Mr. G. MURFITT	Messrs. Wm. Jessop and Sons, Ltd.
Mr. J. G. PEARCE	British Cast Iron Research Association
Mr. C. W. SHORT	John Lysaght, Ltd.
Mr. H. A. SLOMAN	National Physical Laboratory
Mr. G. E. SPEIGHT	The United Steel Companies, Ltd.
Mr. J. E. WELLS	Steel Company of Wales (Lysaght Works), Ltd.
Mr. T. H. WILLIAMS	Messrs. Stewarts and Lloyds, Ltd., Corby
Dr. J. H. WHITELEY	Consett Iron Co., Ltd.
Mr. G. LAMBERT (*Associate Member*)	Institute of British Foundrymen
Mr. T. E. ROONEY (*Associate Member*)	National Physical Laboratory

Liquid Steel Study Group

Mr. G. E. SPEIGHT (*Convener*)	The United Steel Companies, Ltd.
Mr. T. H. ARNOLD	Messrs. Hadfields, Ltd.
Mr. J. D. HOBSON	Brown-Firth Research Laboratories
Mr. I. M. MACKENZIE	Messrs. Colvilles, Ltd.
Mr. G. MURFITT	Messrs. Wm. Jessop and Sons, Ltd.
Mr. H. PADGET	Messrs. Dorman, Long and Co., Ltd.
Mr. M. C. SANDERS	Steel Company of Wales, Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd.
Mr. C. W. SHORT	John Lysaght, Ltd.
Mr. H. A. SLOMAN	National Physical Laboratory
Mr. J. E. WELLS	Steel Company of Wales (Lysaght Works), Ltd.
Mr. A. W. REED	Consett Iron Co., Ltd.

Solid Steel Study Group

Mr. T. E. ROONEY (*Convener*)	National Physical Laboratory
Mr. R. E. LISMER	The United Steel Companies, Ltd.
Mr. I. M. MACKENZIE	Messrs. Colvilles, Ltd.
Mr. D. MARLES	British Cast Iron Research Association
Mr. G. MURFITT	Messrs. Wm. Jessop and Sons, Ltd.
Mr. C. W. SHORT	John Lysaght, Ltd.
Mr. H. A. SLOMAN	National Physical Laboratory
Mr. G. E. SPEIGHT	The United Steel Companies, Ltd.
Mr. J. E. WELLS	Steel Company of Wales (Lysaght Works), Ltd.
Dr. J. H. WHITELEY	Consett Iron Co., Ltd.
Mr. S. W. CRAVEN	I.C.I. (Alkali), Ltd., Northwich.

It will be realized that the co-operating members forming the Sub-Committee and the Study Groups have been actively engaged since the reconstitution of the Sub-Committee. In fact, individual papers have been published under the aegis of the Sub-Committee at intervals during the past two and a half years, as follows :

***" The Determination of Nitrogen in Ferro-Alloys and Other Materials by Direct Nesslerisation without Distillation,"* by W. C. Newell *(Journal of The Iron and Steel Institute*, 1945, No. II, p. 333P).**

SYNOPSIS

The direct method, without distillation, for the colorimetric determination of nitrogen is further applied to the analysis of ferro-alloys by the addition of stabilizing colloids to the Nessler-ammonia coloration. Its application to metallurgical analysis is shown to be extensive, resulting in a far simpler and speedier method for the determination of nitrogen in steel and other alloys.

***" The Rapid Determination of Reactive Oxygen in Open-Hearth Steel,"* by I. M. Mackenzie *(Journal of The Iron and Steel Institute*, 1946, No. II, p. 55P).**

SYNOPSIS

An experimental method of determining the reactive oxygen in liquid steel is described. The results so obtained are shown to correlate with the carbon content and the rate of carbon drop. A formula expressing the relationship is derived enabling the reactive oxygen, during the later stages of the boil, to be calculated or determined graphically from the carbon-drop curve.

***" The Determination of FeO in Steel from the Carbon Drop,"* by R. J. Sarjant *(Journal of The Iron and Steel Institute*, 1946, No. II, p. 265P).**

SYNOPSIS

The paper gives several forms of nomographs applicable to the determinations of FeO in molten steel from the carbon drop. The original basis was developed by Schenck, Riess, and Brüggemann. A variation of equilibrium temperature is included in a revised nomograph, calculated from the free-energy equations of Vacher and Hamilton. Some correlation was found with results of oxygen determinations reported by Bramley, Maddocks, and Tateson. A simpler nomograph was also constructed for use at 1600° C.

A review of the previous work on the determination of FeO in molten steel, and, on the values of the velocity and equilibrium constants required for an accurate definition of the fundamental equation governing the reaction between FeO and carbon, reveals the controversial nature of the subject and the need for further experimental enquiry to establish the accuracy of the data.

***" The Determination of Hydrogen in Liquid Steel,"* by J. E. Wells and K. C. Barraclough *(Journal of The Iron and Steel Institute*, 1947, vol. 155, Jan., p. 27).**

SYNOPSIS

A detailed account is given of five methods of sampling the liquid-steel bath, which have been used at the Brown-Firth Research Laboratories for the determination of the hydrogen content of liquid steel ; these methods include the use of a water-chilled mould, a cast-iron chill mould, and an ingot sample, in addition to the balloon-tube and notched-pencil methods described by Hatfield and Newell. The methods are compared on different types of steel, and conclusions are drawn as to the reliability and applicability of the methods. The best and simplest method appears to be a modified pencil test in which the sample is taken as soon as possible from the mould and then quenched in water.

***"A Micro-Examination of Eight Steels for the Inclusions Sub-Committee,"* by J. H. Whiteley (*Journal of The Iron and Steel Institute*, 1947, vol. 157, Sept., p. 89).**

SYNOPSIS

An investigation for the Inclusions Sub-Committee, of the number, distribution, and nature of the inclusions in a series of eight low-alloy steels, is described. In determining the number of inclusions, counts were made on both lengthwise and crosswise surfaces, it having been previously ascertained from the former, that inclusions not well embedded are liable to be removed in polishing. The way this conclusion was arrived at is shown.

Full details of the counting procedure are presented. The results indicate a direct relationship between the number of inclusions in the steels and their combined sulphur and oxygen contents. A description of the types of inclusions observed in each of the steels is then given, their grain-sizes and macrostructures being also illustrated. In an appendix by G. Murfitt, an X-ray examination of acid-extracted inclusions in these steels is recorded.

The periodic publication of papers by members at unstated intervals represents a departure from the procedure adopted by the Sub-Committee's predecessor, whose recorded work consists of four reports each containing a collection of papers by various members with a suitable introduction and summary by the Chairman of the Sub-Committee. It is intended to continue the policy that papers by individual members will be published as and when they become available. In addition, at intervals of the order of three years, brief reports of the Sub-Committee will be prepared summarizing the papers already published and indicating from time to time the stage of development of the Sub-Committee's work. Some discussion has already taken place on the papers listed above, and further papers by members on various aspects of the subject are now presented, following this introduction. These are listed below :

"*The Determination of Oxygen in Liquid Steel by the Aluminium-Killed Bomb Method*," by G. E. Speight (pp. 390–396).

"*The Determination of Hydrogen in Liquid Steel*," by G. E. Speight and R. M. Cook (pp. 397–405).

"*A Co-operative Examination of a Manganese–Molybdenum Steel*," by T. E. Rooney (pp. 406–409).

"*A Co-operative Examination of a Nickel–Chromium Steel*," by T. E. Rooney (pp. 410–412).

"*A Co-operative Examination of the Distribution of Non-Metallic Inclusions in Billets from a Mild-Steel Ingot*," by T. E. Rooney (pp. 413–415).

In order not to divert attention from the subject matter of these papers, it is not proposed at this stage to summarize the present state of development of the work of the Sub-Committee, but rather to allow this to emerge from the free and frank discussion which the Sub-Committee hopes will arise as a result of presenting their views and objectives. The Sub-Committee will heartily welcome constructive criticism and helpful advice on the development of their aims.

Part II—The Determination of Oxygen in Liquid Steel by the Aluminium-Killed Bomb Method

By G. E. Speight, B.Sc., F.R.I.C., F.I.M.

SYNOPSIS

An examination has been carried out on bomb samples from acid and basic open-hearth casts with the object of studying the reproducibility of the oxygen result obtained by gravimetric, nephelometric, and vacuum-fusion methods. On specially prepared samples agreement of gravimetric-analysis results was good and that of nephelometric analysis only slightly inferior. Recommendations for the taking and analysis of the bomb sample are appended. The gravimetric method provides an alumina residue which is sufficiently pure in low- and medium-carbon heats to obviate the need for this purification, but in other types of material purification of the original residue may be necessary.

Also included in the report are examples of bomb tests taken from acid heats after deoxidation with ferrosilicon as well as from the ladle, in order to determine whether the method is applicable to deoxidized metal. Agreement between gravimetric and vacuum-fusion tests on the same sample confirms the applicability of the bomb test to deoxidized metal baths. Some interesting results of oxygen determinations on a comparable aluminium-killed and non-killed bomb sample are also included.

As part of the co-operative examination of methods for the determination of gases in liquid steel, carried out by the Gases in Liquid Steels Study Group of the Gases and Non-Metallics Sub-Committee, a detailed study has been made of the applications and limitations of the aluminium-killed bomb method for oxygen in liquid steel. This method has previously been examined by Swinden and Stevenson in relation to basic open-hearth steelmaking (Fourth Report of the Oxygen Sub-Committee*). Other investigators have applied the method to other processes, and at various stages during these processes. It was considered, therefore, that a co-operative examination of the method by the Study Group would provide useful information and guidance for workers who may at some time be called upon to use the method.

Paper SM/BB/48/48 of the Gases and Non-Metallics Sub-Committee of the Ingots Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 26th August, 1948.

Mr. Speight is in the Research and Development Department of the United Steel Companies, Ltd., Stocksbridge, near Sheffield.

* *Journal of The Iron and Steel Institute*, 1943, No. II, pp. 397P–407P.

Table I

DATA ON BOMB SAMPLES FOR CO-OPERATIVE EXAMINATION

Sample No.	1	2A	2B	3	J7215/1	J7215/4	L2428	A8472
Quality	Low-carbon steel	Armco iron	Armco iron	Low-carbon steel	..	..	Ordinary plate cast	Low-carbon steel
Furnace	Basic O.H.	Basic O.H.	Basic O.H.	Basic O.H.	Acid O.H.	Acid O.H.	Acid O.H.	Basic O.H.
Condition of Bath when Sampled	Just before FeMn	45 min. before tapping	15 min. before tapping	Just before FeMn	Clear-melted	20 min. before tapping	25 min. before tapping	10 min. before tapping
Analysis of Sample								
Carbon, %	0·06	0·05	0·03	0·07	0·93	0·23	0·21	0·10
Manganese, %	0·15	0·14	0·06	0·20	0·05	0·06	0·07	0·17
Silicon, %	0·008	0·003	0·003	0·009	Trace	Trace	Trace	Trace
Sulphur, %	0·053	0·052	0·041	0·050	0·064	0·065	0·055	0·050
Phosphorus, %	0·018	0·014	0·010	0·014	0·048	0·048	0·032	0·027

The following members of the Gases in Liquid Steels Study Group have taken part in the work described:

I. M. MACKENZIE	Messrs. Colvilles, Ltd., Motherwell
G. MURFITT	Messrs. Wm. Jessop and Sons, Ltd., Sheffield
A. W. REED	Consett Iron Co., Ltd., Consett, Co. Durham
M. C. SANDERS	Steel Company of Wales, Ltd., Port Talbot
H. A. SLOMAN	National Physical Laboratory, Teddington
G. E. SPEIGHT	United Steel Companies, Ltd., Research and Development Department, Stocksbridge
J. E. WELLS	Brown-Firth Research Laboratories (now at Steel Company of Wales, Ltd., Messrs. J. Lysaght, Newport).

The present report deals with the following items:

(*a*) A co-operative examination of a number of bomb samples in which the reproducibility of results obtained by the different investigators is studied.

(*b*) An examination of the application of the method to baths deoxidized with ferro-silicon.

(*c*) Recommendations for the sampling and analysis of the bomb sample.

During the course of this work several features of the analytical and vacuum-fusion methods have required detailed investigation and have been the subject of separate internal reports. Reference is made to some of these points, and the present report is intended to summarize the main findings and recommendations.

Table II

NEPHELOMETRIC DETERMINATIONS OF ALUMINA IN BOMB SAMPLES

Drum-Reading Difference, Using Water/Water Setting of 1·0, 4-cm. Cells, and Ilford Filters No. 607.

Sample No.	1	2A	2B	3	J7215/1	J7215/4	L2428	A8472
Brown-Firth Research Laboratories	0·730	0·785	1·145*	0·778	0·285	0·409	0·510	0·732
Colvilles, Ltd.	0·730 0·729	0·747 0·748	1·420† 1·430†	0·767 0·779	0·323	0·412	0·511	0·715
Wm. Jessop & Sons, Ltd.	0·66 0·65	0·75 0·71	1·10‡ 1·10‡	0·71 0·71	0·30	0·38	0·47	0·68
United Steel Companies, Ltd.	0·686 0·678 0·684 0·702	0·705 0·712 0·737 0·736	1·040‡ 1·138‡ 1·090‡ 1·196‡	0·735 0·738 0·773 0·731 0·741	0·259 0·278	0·338 0·365	0·440 0·470	0·680 0·705
Range	0·65— 0·73	0·705— 0·785	1·430— 1·040	0·710— 0·779	0·259— 0·323	0·338— 0·412	0·440— 0·511	0·680— 0·732
Mean	0·700	0·746	1·196§	0·744	0·289	0·381	0·480	0·702

* Water/water setting of 1·5.
† On half weight, the figures given being derived by multiplying the figures obtained by 2.
‡ A 2-cm. cell, the figures given being derived by multiplying the figures obtained by 2.
§ Omitting the extreme values 1·42 and 1·43, the mean equals 1·115.

EXPERIMENTAL

Experiments were conducted to determine the degree of reproducibility of the analytical results obtained in the co-operating laboratories. With this object in view, eight bomb samples, taken from acid and basic open-hearth casts, were provided for examination by Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd., and by the Consett Iron Co., Ltd.

After cleaning the surfaces, the bombs were sectioned vertically in order to locate possible slag pockets, which were subsequently removed before sampling. Approximately 250 g. of millings were prepared from the lower half of each bomb and, after mixing thoroughly, comparable packets of the millings were circulated for examination in the six co-operating laboratories (*see* Table I).

The determination of aluminium in these test samples was carried out by three main methods: gravimetric, nephelometric, and vacuum fusion.

Table III

GRAVIMETRIC DETERMINATIONS OF ALUMINA (AS PERCENTAGES OF OXYGEN) IN BOMB SAMPLES

	Oxygen, %							
Sample No.	1	2A	2B	3	J7215/1	J7215/4	L2428	A8472
Consett Iron Co., Ltd.								
Before treatment with HF	0·048	0·054	0·080$_5$	0·052	0·013$_5$	0·019	0·029	0·043
After treatment with HF and H_2SO_4	0·046	0·053	0·078$_5$	0·050	0·013	0·018	0·027	0·042
Reprecipitated as phosphate	0·045$_5$	0·053	0·078$_5$	0·049	0·009$_5$	0·017$_5$	0·026	0·039$_5$
Brown-Firth Research Laboratories								
Before treatment with HF	0·045 0·044	0·050 0·051	0·072 0·075	0·047 0·048	0·014 0·013*	0·016 0·018*	0·025 0·025*	0·041 0·044*
After treatment with HF and H_2SO_4	0·048 0·044	0·050 0·051	0·073 0·076	0·046 0·048	0·010 0·011*	0·016 0·017*	0·025 0·025*	0·041 0·042*
Reprecipitated as oxine	0·045 0·045	0·049 0·050	0·073 0·075	0·046 0·048	0·008 0·006*	0·015 0·015*	0·023 0·022*	0·041 0·039*
Colvilles, Ltd.								
Before treatment with HF	0·049† 0·045	0·059$_5$† 0·053$_5$	0·085† 0·083	0·063† 0·053$_5$	..	..	..	..
After treatment with HF and H_2SO_4	0·049† 0·045	0·059$_5$† 0·053$_5$	0·086$_5$† 0·081$_5$	0·063† 0·053	0·014	0·019	0·027	0·043
Reprecipitated as oxine	0·042† 0·044	0·050$_5$† 0·051$_5$	0·078† 0·075	0·051$_5$† 0·050$_5$	0·012	0·018	0·026	0·041$_5$
Guest Keen Baldwins Iron and Steel Co., Ltd.								
Before treatment with HF	0·044	0·050	0·077	0·049	0·016	0·013	0·026	0·041
Wm. Jessop and Sons, Ltd.								
Before treatment with HF	..	..	..	..	0·013	0·018	0·026	0·041
After treatment with HF and H_2SO_4	0·045 0·045	0·052 0·053	0·082 0·080	0·050 0·051	0·009	0·016	0·025	0·041
Reprecipitated as phosphate	..	..	..	..	0·009	0·016	0·024	0·041
United Steel Companies, Ltd.								
Before treatment with HF	..	..	..	..	0·008 0·011	0·018 0·017$_5$	0·027$_5$ 0·027	0·040 0·040
After treatment with HF and H_2SO_4	0·044 0·042	0·054	0·081$_5$ 0·077$_5$	0·056$_5$ 0·051	0·007$_5$ 0·010$_5$	0·016 0·017$_5$	0·027 0·028	0·040 0·042
Reprecipitated as oxine	0·042$_5$ 0·043	0·052	0·079$_5$ 0·078$_5$	0·053 0·050	0·006	0·015$_5$	0·026	0·039
Reprecipitated as hydroxide	..	..	..	..	0·011	0·016$_5$	0·025	0·041
Range								
Before treatment with HF	0·044– 0·049	0·050– 0·059$_5$	0·072– 0·085	0·047– 0·063	0·008– 0·016	0·013– 0·019	0·025– 0·029	0·040– 0·043
After treatment with HF and H_2SO_4	0·042– 0·049	0·050– 0·059$_5$	0·073– 0·086$_5$	0·046– 0·063	0·007$_5$ 0·014	0·016– 0·019	0·025– 0·028	0·040– 0·043
Reprecipitated	0·042– 0·045$_5$	0·049– 0·053	0·073 0·079$_5$	0·046– 0·053	0·006– 0·012	0·015– 0·018	0·022– 0·026	0·039– 0·041$_5$
Mean								
Before treatment with HF	0·046	0·053	0·079	0·051$_5$	0·012$_5$	0·017	0·026$_5$	0·041$_5$
After treatment with HF and H_2SO_4	0·045	0·053$_5$	0·079$_5$	0·052	0·010$_5$	0·017	0·026$_5$	0·041$_5$
Reprecipitated	0·044	0·051$_5$	0·077	0·049$_5$	0·009	0·016	0·024$_5$	0·040$_5$

* Sample dissolved in perchloric acid. † Determinations carried out on 5-g. samples.

Gravimetric Method

The gravimetric method involves an acid decomposition of a weighed portion of the milled sample, followed by filtration of the solution to collect the insoluble residue, which is substantially alumina but which has subsequently been purified by conventional chemical procedures. Details of the acid extraction are given in Appendix I, which includes also the Study Group's recommendations for the taking of samples.

In the results which are given in Table III, the following three measurements of the alumina residue are recorded: (i) Impure residue, before treatment with hydrofluoric and sulphuric acids; (ii) after removal of any silica present, by means of hydrofluoric and sulphuric acids; and (iii) after re-precipitation, either as phosphate or as hydroxyquinoline complex.

Nephelometric Method

In the nephelometric method the photo-electric cell measurement of the depth of turbidity due to insoluble alumina in a solution is obtained by acid decomposition of the sample. The experimental details are given in Appendix I.

The measurements were carried out in the Hilger absorptiometer and are reported in terms of instrument readings (Table II). It would be necessary in practice to construct a suitable calibration curve connecting such readings with oxygen or alumina results derived by some alternative method. The alternative method may well be the gravimetric method or the vacuum-fusion method.

Vacuum-Fusion Method

Many references to the vacuum-fusion method have been made in previous reports of the Oxygen Sub-Committee. During the course of this work it has been found necessary to modify slightly the vacuum-fusion procedure, especially in the case of aluminium-treated bomb samples containing over 0·025% of oxygen as alumina. In the particular apparatus used for these tests, it appeared that the presence of aluminium of the order of 1% in the bomb sample gave rise to low oxygen values, possibly due to volatilization and adsorption effects. The latter effects, however, were entirely eliminated by melting and reducing in the presence of metallic tin, which prevents the volatilization of aluminium.

The vacuum-fusion values given below have been obtained by melting the samples in the presence of tin:

Sample No.	Oxygen, %
1	0·037$_5$
2*A*	0·053
2*B*	0·074
3	0·048$_5$
*J*7215/1	0·006$_5$
*J*7215/4	0·016
*L*2428	0·027
*A*8472	0·041

EXAMINATION OF KILLED SAMPLES

In steelmaking processes it is possible at certain stages, particularly the later stages of the acid open-hearth process, for oxygen to exist in forms other than dissolved or free ferrous oxide. The existence of silica under such conditions has been stated. Such forms may not be completely converted to alumina in the relatively quick reaction in the bomb sample. These considerations apply in a greater degree to partially or fully killed steel at, or during, tapping. It seemed desirable, therefore, to examine the applicability of the bomb method to such conditions.

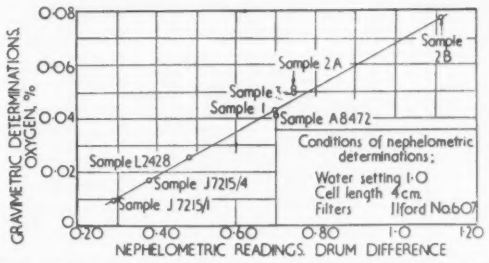

Fig. 1—Comparison of gravimetric alumina determinations and nephelometric determinations

This investigation has been carried out jointly by the Research and Development Department of the United Steel Companies, Ltd., and by the Consett Iron Co., Ltd., on bomb samples of acid steel. Several series of bomb samples, both with and without aluminium killing, taken at stages before and after ferro-silicon additions, have been examined by chemical and vacuum-fusion methods, with the results given in Appendix II.

RESULTS

Only brief comment will be made on the detailed results presented in the tables and graphs, which are given for record purposes and for the consideration of other workers in this field.

It is considered that the reproducibility of gravimetric oxygen results between the co-operating laboratories is satisfactory, particularly in the high oxygen ranges where contamination of the initial residue is slight. The variation in one sample, *J*7215/1, is greater than is considered desirable, but this sample has the lowest oxygen content with the highest degree of contamination of the initial residue. Direct oxygen values obtained on such a sample from the initial unpurified residue would not be acceptable. On the remaining samples the oxygen value given by the initial unpurified residue would be satisfactory for routine works purposes.

The full range of nephelometric readings by the various laboratories is not so close as would be desirable, but is considered satisfactory. Certain laboratories seem to have consistent tendencies for

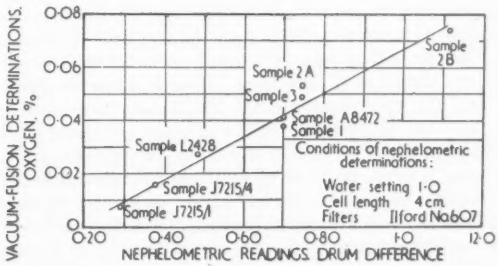

Fig. 2—Comparison of vacuum-fusion oxygen determinations and nephelometric determinations

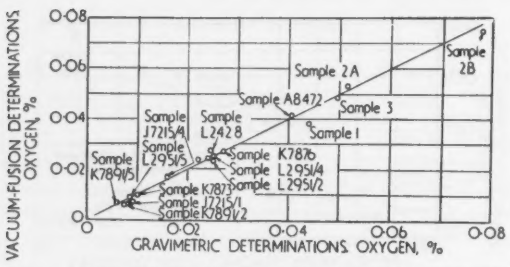

Fig. 3—Comparison of vacuum-fusion and gravimetric oxygen determinations

slightly high, or low, results which may indicate that part, at least, of the differences between operators is due to the instrument characteristics. In applying the nephelometric method to the analysis of aluminium-killed bomb samples, it would be necessary for each worker to construct a separate calibration curve for each instrument in order to convert the nephelometric readings to oxygen percentages. Two such curves are shown in Figs. 1 and 2, which relate the mean nephelometric readings with the oxygen percentages determined gravimetrically and by vacuum fusion respectively. The agreement is such as to indicate that the nephelometric method should be applicable to the routine examination of the oxygen content of liquid-steel baths. The relation between vacuum-fusion and gravimetric oxygen determinations is given in Fig. 3.

A number of interesting comments are possible on the results of silicon-treated baths, given in Appendix III, in addition to the obvious conclusion that, irrespective of whether the bath is, or is not, deoxidized, the oxides present are converted to alumina during sampling by the bomb method, and that, consequently, the bomb sample is a suitable means of determining oxygen in liquid steel at all stages of the process. The metallurgical significance of certain of the results, particularly in those bomb samples with no aluminium, has been the subject of considerable discussion. Thus, the fact that the results indicate that before ferro-silicon addition the bath contains a certain amount of oxygen as silica, must not be taken as evidence that such is the case. It is possible that such silica as is shown in these initial residues was, in fact, formed during cooling from steelmaking temperatures by the relative changes in the carbon–oxygen and silicon–oxygen equilibria.

SUMMARY AND CONCLUSIONS

The results of a co-operative examination of the aluminium-bomb method for oxygen in liquid steel indicate that the method may be applied to liquid-steel baths, either acid or basic, at all stages throughout the working of the heat. Except in basic heats of low- and medium-carbon steels, it may be necessary to carry out purification of the original acid-extracted residue in order to obtain accurate oxygen results by the gravimetric method of analysis. Reproducibility of results by gravimetric analysis is good and that of nephelometric results only slightly inferior, although the variations in nephelometric results are due largely to the characteristics of the different absorptiometers used in this method.

Appendix I

RECOMMENDATIONS FOR THE BOMB-SAMPLING METHOD FOR OXYGEN IN LIQUID STEEL

The following details of apparatus and procedure of the bomb-sampling method for the determination of oxygen in liquid steel are the recommendations of the Gases in Liquid Steels Study Group of the Gases and Non-Metallics Sub-Committee.

Sampling Apparatus

(a) *Bomb Mould*—The bomb mould is described and illustrated in the Fourth Report of the Oxygen Sub-Committee (pp. 400P and 401P and Fig. 19).

(b) *Mild-Steel Cap*—The mild-steel cap is of 27-gauge deep-pressing quality mild steel; a suitable form of pressing tool is described in the Fourth Report (p. 401P, Fig. 20).

(c) *Clamping Ring and Rod*—The assembled mould is best supported for the actual sampling by a wedge fit in a clamping ring at the end of a long rod (10 to 12 ft. in length); a suitable form of clamping ring is illustrated in the Fourth Report (p. 400P, Fig. 19).

Sampling Procedure

The bomb mould is charged with a crumpled ball of 5 g. of 26 to 30-gauge pure aluminium wire, which is thus uniformly distributed throughout the spherical space when the two halves of the mould are clamped together. The mild-steel cap is then placed in position and the bomb is inserted in the clamping ring. The bomb is rapidly but carefully slagged, the top of the cap being left unslagged, and then plunged quickly through the slag into the metal in the middle of the bath. This is best accomplished by balancing the rod carrying the bomb on the sill of the furnace door; the bomb may then be plunged through the slag in an inverted position and reversed to an upright position in the metal bath. The bomb cap is quickly melted and the filling of the mould with liquid steel is indicated by a slight 'pull' on the rod. It is important that the mould should be filled completely to avoid slag contamination, and also that it should be withdrawn from the bath as soon as it is judged to be filled. With large, fixed, 80-ton open-hearth furnaces the time for filling the bomb is 10 sec., the samples being taken from the centre of the bath.

The bomb sample is immediately taken from the mould and quenched from black heat.

Drilling the Sample

The lower half of the bomb is ground to remove surface scale and the cleaned surface is drilled at one or more positions. A $\frac{1}{2}$-in. drill is used, the first drillings to a depth of $\frac{1}{4}$ in. are discarded, and the sample for analysis is taken at a depth of between $\frac{1}{4}$ and $\frac{3}{4}$ in. Drillings taken from the centre of the bomb may sometimes be contaminated with entrapped slag in central pockets.

Analysis of Drillings

(1) *Direct Determination of Alumina*—The extraction of alumina from the sample is carried out as follows: Dissolve 10 g. of sample in 100 ml. of hydrochloric acid (sp. gr. 1·16). Add, by drops, 25 ml. of nitric acid (sp. gr. 1·42) and digest for 5 min. or until

the solution clears. Dilute with 100 ml. of hot water and filter on a paper pad, washing with dilute hydrochloric acid (1 : 4), 3% sodium carbonate solution, dilute hydrochloric acid (1 : 4), and finally with water. Ignite and weigh. Treat with sulphuric and hydrofluoric acids and again ignite and weigh.

Speedy solution of the drilled sample may be obtained by dissolving 10 g. of drillings in a mixture of 60 ml. of perchloric acid, 40 ml. of nitric acid, and 40 ml. of water. When nearly dissolved, add 40 ml. of hydrochloric acid, and when completely dissolved, boil for 1 min., dilute with 100 ml. of boiling water, and add a little pulp. Complete the estimation exactly as in the normal direct method.

An addition of platinic chloride to the solution also serves to shorten the decomposition time, particularly in the case of low-carbon materials.

The oxygen content of the sample is obtained from the weight of residue obtained in the acid extraction. Experience shows that this is completely satisfactory only with basic open-hearth qualities of low carbon content and free from alloying elements. With certain acid steels, and high-carbon and alloyed materials of both acid and basic types, the extracted residue sometimes may be contaminated and purification may be necessary. This can be carried out by conventional chemical procedures involving precipitation of aluminium as phosphate or as 8-hydroxyquinoline.

(2) *Nephelometric Method*—Dissolve 2 g. of drillings in 30 ml. of a mixture of 30 ml. of orthophosphoric acid (85%), 90 ml. of nitric acid (sp. gr. 1·42), and 80 ml. of water. Boil for 3 min., add 10 ml. of 10% ammonium persulphate solution, and continue boiling for a further 3 min. Cool to room temperature, dilute to 50 ml. with 2% nitric acid and mix thoroughly. Transfer the solution to a 4-cm. cell and measure the light absorption in a Spekker photo-electric absorptiometer, using Ilford filters, No. 607, and an instrument setting of water-to-water 1·0.

The alumina content of the sample is then obtained by reference to a calibration chart connecting the extinction coefficient (drum reading) and the alumina content previously determined by alternative methods.

It is important that the calibration chart should be derived from samples of similar quality. High-carbon or alloy contents would necessitate the use of a calibration curve obtained on such samples.

Owing to the difficulties encountered in obtaining satisfactory calibration curves, the method is less precise than the gravimetric procedures. It is recommended, therefore, only for routine purposes where large numbers of determinations are to be carried out in the shortest possible time.

Appendix II

CAST DATA OF ACID-STEEL BOMB SAMPLES

Cast *L*2951

Time	Analysis, %
1.05 P.M. (melted)	0·70 C, 0·055 S, 0·031 P
2.10 P.M.	0·47 C, 22·4 slag iron
3.15 P.M.	0·18$_5$ C, 19·5 slag iron
3.38 P.M.	0·16 C, 17·0 slag iron
3.40 P.M.	0·15 C, 0·08 Mn, 0·015 Si, 0·054 S, 0·032 P, 16·7 slag iron.

5 cwt. ferro-silicon added. No. 2 bomb sample

3.55 P.M.	0·14$_5$ C, 0·08 Mn, 0·215 Si, 0·054 S, 0·032 P, 16·4 slag iron.

Tapped. No. 4 bomb sample
No. 5 bomb sample (from ladle)

Bath Addition : 5 cwt. ferro-silicon
Ladle Additions : 9½ cwt. ferro-manganese
120 lb. Alsimin
Pit-Sample Analysis, % : 0·205 C, 0·69 Mn, 0·18 Si, 0·055 S, 0·034 P
Teeming : Uphill.

Cast *K*7891

Time	Analysis, %
11.35 A.M. (melted)	0·95 C, 0·061 S, 0·041 P
12.40 P.M.	0·78 C, 16·7 slag iron
1.15 P.M.	0·64 C, 17·8 slag iron
1.35 P.M.	0·60 C, 17·6 slag iron
2.00 P.M.	0·51 C, 17·0 slag iron
2.20 P.M.	0·45$_5$ C, 0·08 Mn, 0·025 Si, 0·060 S, 0·040 P, 18·2 slag iron

3 cwt. ferro-silicon added. No. 3 bomb sample

2.40 P.M.	0·45 C, 0·09 Mn, 0·15 Si, 0·060 S, 0·040 P, 18·9 slag iron

Tapped. No. 5 bomb sample
No. 6 bomb sample (from ladle)

Bath Addition : 3 cwt. ferro-silicon
Ladle Additions : 12½ cwt. ferro-manganese
3 lb. aluminium
75 lb. coal
Pit-Sample Analysis, % : 0·58 C, 0·79 Mn, 0·13 Si, 0·060 S, 0·041 P
Teeming : Direct

Cast *K*7938

Charge : 22 tons pig iron, 68 tons 18 cwt. scrap

Time	Analysis, %
5.45 A.M.	Commenced charging ...
11.30 A.M.	Finished charging ...
3.00 P.M.	Melted 0·65 C, 0·052 S, 0·029 P, 17 slag iron
3.55 P.M.	0·36 C
4.35 P.M.	0·19$_5$ C
5.00 P.M.	0·16 C, 0·09 Mn, 0·015 Si, 17·0 slag iron

No. 1 bomb sample (no Al)
No. 2 bomb sample (5g. Al)

5.05 P.M.	6 cwt. ferro-silicon added.
5.20 P.M.	0·15$_5$ C, 0·10 Mn, 0·18 Si, 16·6 slag iron

No. 3 bomb sample (no Al)
No. 4 bomb sample (5 g. Al)

5.25 P.M. Tapped. Ferro-manganese and Alsimin added
No. 6 bomb sample (no Al) (from ladle)
No. 7 bomb sample (5 g. Al) (from ladle)

Bath Additions : 24 cwt. ore
Limestone
6 cwt. ferro-silicon
Ladle Additions : 12½ cwt. ferro-manganese
150 lb. Alsimin
25 lb. anthracite
Pit-Sample Analysis, % : 0·25 C, 0·63 Mn, 0·17 Si, 0·052 S, 0·032 P
Teeming : Uphill.

Cast *K*7952

Time	Analysis, %
4.50 A.M. (melted)	1·03 C, 0·20 Mn, 0·13 Si, 0·048 S, 0·034 P, 19·5 slag iron

6.00 A.M. 0·65 C, 0·12 Mn, 0·09 Si, 17·3 slag iron
6.35 A.M. 0·53 C, 0·13 Mn, 0·11 Si, 15·7 slag iron
6.55 A.M. 0·47 C, 0·15 Mn, 0·11 Si
No. 1 bomb sample (no Al)
No. 2 bomb sample (5 g. Al)
7.00 A.M. 6 cwt. ferro-silicon added. 0·47 C, 0·15 Mn, 0·29 Si
No. 3 bomb sample (no Al)
No. 4 bomb sample (5 g. Al)
7.10 A.M. Tapped. No. 5 bomb sample (5 g. Al) (from ladle)

Bath Addition : 6 cwt. ferro-silicon
Pit-Sample Analysis, % : 0·52 C, 0·70 Mn, 0·29 Si, 0·049 S, 0·037 P
Teeming : Uphill.

Appendix III

OXYGEN CONTENTS AFTER FERRO-SILICON ADDITION TO ACID STEEL

Cast *K*7873

Details of Cast : 90-ton acid open-hearth.
Addition : 3 cwt. ferro-silicon added 15 min. before tapping.
Sample : Aluminium-killed bomb sample taken after addition of ferro-silicon and 10 min. before tapping.
Analysis of Bath, % : 0·37 C, 0·08 Mn, 0·11 Si, 0·048 S.
Oxygen Content of Bomb Sample (Gravimetric Alumina) :

(*a*) Initial residue	0·010%
(*b*) After removal of silica	0·010%
(*c*) After purification	0·010%
(Consett value	0·011%)

Total Oxygen (Vacuum-Fusion) : 0·009%.

Cast *K*7876

Details of Cast : 90-ton acid open-hearth.
Addition : 6 cwt. ferro-silicon added 15 min. before tapping.
Sample : Aluminium-killed bomb sample taken after addition of ferro-silicon and 10 min. before tapping.
Analysis of Bath, % : 0·17 C, 0·05 Mn, 0·15 Si, 0·050 S.
Oxygen Content of Bomb Sample (Gravimetric Alumina) :

(*a*) Initial residue	0·027%
(*b*) After removal of silica	0·027%
(*c*) After purification	0·027%
(Consett value	0·026%)

Total Oxygen (Vacuum-Fusion) : 0·026$_5$%.

OXYGEN CONTENTS BEFORE AND AFTER FERRO-SILICON ADDITION

Cast *L*2951

Details of Cast : 90-ton acid open-hearth.
Samples : No. 2, before ferro-silicon addition.
No. 4, after addition of 5 cwt. ferro-silicon.
No. 5, from ladle, after addition of 9½ cwt. ferro-manganese and 120 lb. Alsimin.

Analysis of Samples

	No. 2	No. 4	No. 5
Carbon, %	0·15	0·14$_5$	0·20$_5$
Manganese, %	0·08	0·08	0·69
Silicon, %	0·015	0·215	0·18
Sulphur, %	0·054	0·054	0·055
Phosphorus, %	0·032	0·032	0·034

Oxygen Contents, %

	No. 2	No. 4	No. 5
(*a*) Initial residue (grav., United Steels)	0·026	0·029	0·011
(*b*) After silica removal (grav., United Steels)	0·026	0·029	0·008
(*c*) After purification : Grav., Consett	0·023$_5$	0·024	0·008$_5$ / 0·008
Grav., United Steels	0·026	0·025	0·009
Vac. fus. United Steels	0·023	0·025	0·008

Cast *K*7938

Details of Cast : 90-ton acid open-hearth.
Samples : (1) Before ferro-silicon addition.
(2) After addition of 6 cwt. ferro-silicon.
(3) From ladle, after additions of ferro-manganese, Alsimin, and anthracite.

Analysis of Samples

	Sample (1)	Sample (2)	Sample (3)
Carbon, %	0·16	0·15$_5$	0·25
Manganese, %	0·09	0·10	0·63
Silicon, %	0·015	0·18	0·17

Oxygen Contents, %

	Sample (1)	Sample (2)	Sample (3)
(*a*) Initial residue (grav., United Steels)	0·014,* *0·023*	0·022,* *0·022*	0·006,* *0·007*
(*b*) After silica removal (grav., United Steels)	Nil, *0·023*	Nil, *0·021*	0·005, *0·006*
(*c*) After purification : Grav., Consett	0·001, *0·022*	0·001, *0·023*	0·006, *0·007*
Grav., United Steels	Nil, *0·025*	Nil, *0·022*	0·006, *0·008*
Vac. fus., United Steels	0·016, *0·024*	0·020, *0·023$_5$*	0·005$_5$, *0·006$_5$*

Cast *K*7952

Details of Cast : 90-ton acid open-hearth.
Samples : (1) Before ferro-silicon addition.
(2) After addition of 6 cwt. ferro-silicon.
(3) From ladle.

Analysis of Samples

	Sample (1)	Sample (2)	Sample (3)
Carbon, %	0·47	0·47	0·52
Manganese, %	0·15	0·15	0·70
Silicon, %	0·11	0·29	0·29
Sulphur, %	0·048	0·049	0·049
Phosphorus, %	0·036	0·037	0·037

Oxygen Contents, %

	Sample (1)	Sample (2)	Sample (3)
After purification : Grav., Consett	0·001, *0·008*	0·001, *0·008*	... *0·007*
Vac. fus., United Steels	0·004, *0·008*	0·007$_5$, *0·008*	... *0·006$_5$*

(Figures in roman refer to unkilled bomb samples, those in italic refer to aluminium-killed bomb samples.)

* Based on alumina oxygen factor. As these residues are substantially silica, the silica-oxygen factor should be applied ; the resulting oxygen values would then be slightly higher.

Part III—The Determination of Hydrogen in Liquid Steel

By G. E. Speight, B.Sc., F.R.I.C., F.I.M., and R. M. Cook, B.Sc.(Eng.), A.Met.

SYNOPSIS

Previous work on the determination of hydrogen in solid and liquid steel and on the development of sampling methods for hydrogen in liquid steel is reviewed. Detailed accounts are given of two methods which have been used in the authors' laboratories. The 'sealed mould' is a closed sampling tube in which account is taken of the hydrogen evolved from the sample during cooling. The 'chilled pencil' is an open tube in which the sample is rapidly cooled. From both types of sample the hydrogen is extracted by vacuum heating at 750° C. The modified extraction apparatus is described in detail.

Results are given for low-alloyed open-hearth and electric-arc steels. The hydrogen contents of basic open-hearth casts are, in general, higher than those of basic electric or acid open-hearth casts, average figures being 8 ml./100 g. for basic open-hearth and 6 ml./100 g. for basic electric arc. Brief reference is made to the effects of metal composition on these values.

THE determination of hydrogen in solid steel has been established and practised for many years. Together with oxygen and nitrogen, the hydrogen content of iron or steel may be determined by the vacuum-fusion method, which has been described fully in previous reports of the Oxygen Sub-Committee.[1–3] In this method the sample is melted in a graphite crucible *in vacuo* at approximately 1650° C.; the oxides in the steel are reduced by carbon to form carbon monoxide, so that the evolved gas consists essentially of carbon monoxide, hydrogen, and nitrogen. In this field the work of Sloman is outstanding. He showed that, by careful attention to detail, so that the 'blank' values are reduced to negligible amounts, it is possible to obtain very accurate values for the hydrogen content of solid-steel samples by the vacuum-fusion method.

It was later shown by Sloman,[3] and subsequently developed by Newell,[4] that in order to obtain the hydrogen content of steel, fusion of the sample was unnecessary, and that hydrogen could be evolved from steel by heating *in vacuo* at temperatures greater than 650° C. This resulted in a simplification of apparatus, and several forms of the 'low-temperature' or 'vacuum-heating' method for hydrogen have been described.[5] In most of these methods relatively small samples are employed, and as the volume of the evolved gas, which is substantially hydrogen, is very small, it is usually measured in a McLeod gauge at low pressure. These methods continue to be used for solid samples and have given useful information on the hydrogen content of many cast and rolled materials.

The relative rapidity of hydrogen evolution at temperatures greater than 650° C., as in the vacuum-heating methods, suggests that rolled steel products which have undergone long soaking at elevated temperatures and large reductions in section will have a considerably lower hydrogen content than they had in the liquid state or immediately after casting. Moreover, it has been shown that many cast materials evolve hydrogen on standing at room temperatures. It seems reasonably definite, therefore, that liquid steel should contain larger amounts of hydrogen than the ultimate finished product. A knowledge of the hydrogen content of the steel in the liquid stage is perhaps of greater importance than in the finished material. In seeking to determine the hydrogen content of liquid steel, using ordinary methods of sampling, it is found that considerable loss of hydrogen occurs between liquid and solid states, and that the residual-hydrogen content of the sample depends on a number of factors, such as composition, rate of cooling, etc., as well as on the initial hydrogen content in the liquid state. Thus, whilst the hydrogen content of solid steel can be determined accurately, the fugitive nature of hydrogen during the sampling of liquid steel is the major problem in all methods for the determination of hydrogen in liquid steel.

The problem has been approached in many ways; the obvious way is to sample and determine the hydrogen content whilst the metal is still in the liquid state. On this basis, Hare, Peterson, and Soler[6] developed a closed evacuated pipette-like apparatus which was inserted into a large spoon of molten metal. The hot liquid metal penetrated the diaphragm closing the pipette, and a definite amount of metal entered and was chilled in the pipette. The volume of gas evolved during this operation was recorded, and was found to relate to the hydrogen and oxygen contents of the liquid metal. This apparatus was rather large and perhaps unwieldy, so that Newell[7] developed a 'balloon-tube method' which used the same principle, but in which the evacuated pipette was only 9 or 10 in. in length and was charged with nitrogen to just below atmospheric pressure. The gas evolved from, and the gas remaining in, the solid sample which chilled inside the pipette was removed and analysed for the hydrogen content in the original liquid state.

An alternative approach is the standard one of rapid quenching, in order to retain the high-temperature state in regard to hydrogen and to suppress the changes that occur at normal cooling rate. On this principle Newell[7] has described a 'chilled-pencil test' in which the liquid steel was poured into a cast-iron mould and a portion of the chilled sample was then taken for vacuum-heating extraction of its hydrogen. On many samples, largely of alloy steel, the hydrogen results obtained for the chilled pencil have shown reasonable correlation with the results of the balloon-tube method. Herasymenko and Dombrowski[8] found that it was necessary to pour the liquid steel into a

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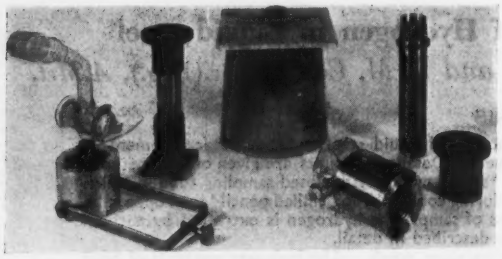
Mr. Speight and Mr. Cook are in the Research and Development Department of the United Steel Companies, Ltd., Stocksbridge, near Sheffield.



Sealed mould Chilled-pencil mould Modified sealed mould

Fig. 4—Types of moulds

sample tube, which was cooled in water and immediately sealed, so that any gas evolved during the later stages of cooling was collected in the enclosed space above the solid sample. The determination of total hydrogen consisted, therefore, in an analysis of the gas atmosphere above the solid sample as well as vacuum-heating extraction of the hydrogen remaining in the solid sample. Wells and Barraclough[9] have described a number of forms of quenched samples, of the open-tube type, both water chilled and cast-iron chilled. Mackenzie[10] has used a water-chilled sample similar to that of Herasymenko and Dombrowski and to that described later in this paper.

The work described in this paper has been confined to the quenched type of sample, as this appeared to offer the simplest means of obtaining a satisfactory sample for the determination of hydrogen in liquid steel, as well as for the simultaneous determination of hydrogen and oxygen.

SAMPLING METHODS

Many forms of sampling tubes, of both the open and closed types, have been used in the early stages of this work. Some have been partial successes only and were discarded. Of these mention might be made of the following :

(*a*) A copper tube, 6 × ½-in. dia., closed at one end, the open end being flanged to enable the tube containing the sample to be sealed by a lead washer connecting to a similarly flanged metal vacuum tap. The joint was completed by a screwed steel collar. The tube was placed upright in a cold-water bath and the liquid steel was poured into the tube through a refractory cone ; the sample tube was then immediately sealed. The hydrogen value was thus obtained in two fractions, *i.e.*, that evolved during cooling, and that remaining in the solid-steel sample. Many trials were carried out on this type of sample tube, but the practical difficulties of ensuring a tight seal were such that there were many unsatisfactory tests.

(*b*) A heavy cast-iron split mould, similar to the carbometer mould, was somewhat unsatisfactory with carbon-steel melts as the rate of cooling was not sufficiently rapid to avoid excessive surface oxidation ; this necessitated considerable surface preparation before the sample could be analysed for its remaining hydrogen.

(*c*) A thin-walled water-jacketed steel split mould, similar in dimensions to the carbometer mould, gave more success. This had an automatic circulating-water device to assist cooling.

(*d*) A small squat cast-iron mould, with internal dimensions approximately 2 by 1-in. dia., containing a crumpled ball of fine aluminium wire, gave reasonable results on samples of high oxygen content.

It became clear at a later stage in the work that some form of the closed-tube sample was essential, as the amount of hydrogen that could be evolved in the early stages from samples cast in open moulds was often quite considerable. Ultimately two forms of sample tube were standardized, one a closed type and the other an open type, and these have been used with success. They are illustrated in Fig. 4 and may be described briefly as follows :

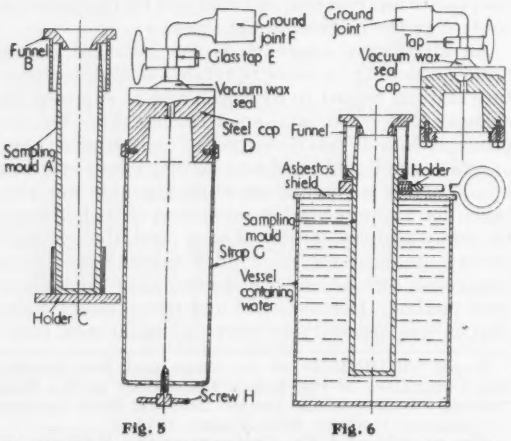


Fig. 5 Fig. 6

Fig. 5—Diagrammatic illustration of the sealed mould
Fig. 6—Diagrammatic illustration of the modified sealed mould

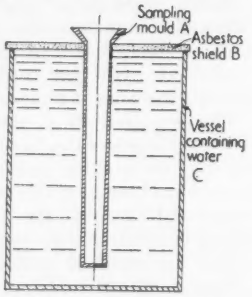


Fig. 7—Diagrammatic illustration of the chilled-pencil mould

The Sealed Mould—This mould is very similar to the tube described by Herasymenko and Dombrowski[8] and to that used by Mackenzie.[10] It consists of a stainless tube, 6 in. long, closed at one end and tapering from $1\frac{1}{8}$ to $\frac{7}{8}$ in. internal dia. to permit easy withdrawal of the sample (*see* Fig. 5). The open end of the mould terminates in a conical joint, accurately ground to fit a corresponding taper in a steel cap (*D*) to which are attached a glass tap (*E*) and a ground joint (*F*). In order to ensure a gas-tight seal between the mould and the cap, the latter is fitted with a strap (*G*) and a screw (*H*), which are used to clamp the sample tube

firmly into the metal cap after the liquid steel has been cast into the tube. Accurate pouring of the liquid steel into the mould is facilitated by the use of a mild-steel funnel (*B*), coated with graphite, which serves also to shield the ground joint from splashes of molten metal during sampling.

The design of the sealed mould has been modified in the later work in order to facilitate and expedite the sealing and cooling operations. The strap and screw arrangements have been replaced by means of a coarse-pitch thread which fits into a corresponding threaded ring, secured to the lower face of the cap, as shown in Fig. 6. Sealing of the mould is thus effected merely by placing the cap in position and screwing down tightly. The sample tube is immersed in the bath of water as before, supported by an asbestos shield, and is fitted with a handle so that the cap can be screwed into position on the tube without removing from the water-cooling bath.

The Chilled-Pencil Mould—This mould, which is shown diagrammatically in Fig. 7, comprises a stainless-steel tube (*A*), 6 in. long, with bore tapering from $\frac{7}{16}$ to $\frac{9}{16}$ in., closed at one end, the open end being funnel-shaped to facilitate pouring of the liquid sample. For sampling liquid steel the mould is supported on an asbestos shield (*B*) and suspended within a water-cooling bath (*C*).

It will be seen, therefore, that experiments have been carried out with both the open and closed types of sampling tubes and considerable data have been accumulated on the use and limitations of these two types of sample.

VACUUM-EXTRACTION METHODS

The apparatus used for the low-temperature vacuum extraction of hydrogen in steel has been described in a previous report of the Oxygen Sub-Committee.[5] This apparatus was designed initially for the analysis of small samples, approximately 10 to 15 g. in weight, from which only very small volumes of gas are normally obtained. The total volume of the gas evolved, substantially hydrogen, is measured at low pressure in a modified McLeod gauge.

For the hydrogen content of liquid steel this form of apparatus suffers from two major disadvantages :

(*a*) From certain samples, the gas extracted at 650° to 700° C. has been found to contain small amounts of carbon monoxide and nitrogen with a hydrogen content of the order of 90 to 95%. With forged materials of low hydrogen content, this does not introduce any serious errors, but with liquid-steel samples the amounts of other gases in the extracted ' hydrogen ' are frequently quite appreciable, particularly when the steel samples are taken during the course of refining. For accurate results full analysis of the extracted gases is desirable.

(*b*) Water vapour is frequently found in gases extracted from solid steel. This probably arises by reaction between the diffusing hydrogen and oxygen either in the sample or in the oxide surface film, and there appears to be no regularity in regard to the amount of water vapour that may arise from a particular sample. As water vapour in the extracted gases can have arisen only from hydrogen in the steel, its volume must be recorded in order to obtain a true hydrogen content. In the foregoing vacuum-extraction apparatus, account was taken of the water vapour in the gas by measuring the total volume in the modified McLeod gauge at such a pressure that condensation of water vapour did not occur. However, with the larger samples used for liquid-steel sampling, and the resulting larger amount of hydrogen to be measured, the possible amount of water vapour that can be formed has also increased and alternative means of correcting for it have become necessary.

In view of the above limitations a modified low-temperature extraction apparatus has been developed for this work on hydrogen in liquid steel. This is illustrated diagrammatically in Fig. 8. The furnace tube is capable of dealing with samples up to 1-in. dia., and larger tubes are available for samples up to 2-in. dia. Errors due to water vapour were initially overcome by passing the extracted gases over metallic manganese at 950° C. There was, however, fairly

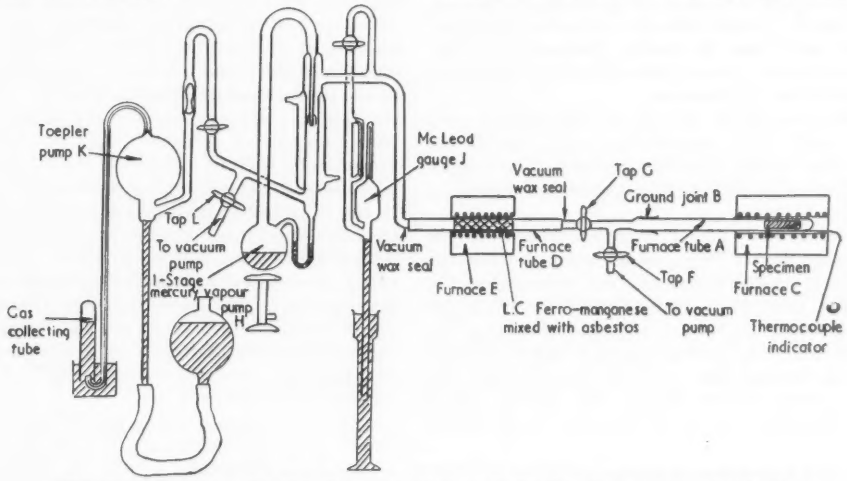


Fig. 8—Apparatus for the determination of hydrogen by vacuum heating

rapid reaction between the manganese and the silica tube at this temperature, with frequent failures. In later tests, low-carbon ferro-manganese mixed with asbestos and heated to 750° C. has proved entirely satisfactory in ensuring the decomposition of water vapour and the absence of reaction with the furnace tube.

The main features of the modified vacuum-heating apparatus and its mode of operation are evident from the diagrammatic sketch, Fig. 8. The furnace tube is heated by a simple wire-wound element and is connected to the remainder of the apparatus *via* a ground joint (*B*). The extracted gases are removed from the furnace and passed over heated ferro-manganese in the furnace tube (*D*) by means of a single-stage mercury-vapour pump (*H*) and then forward into the Toepler pump (*K*), from which they are subsequently removed for analysis. A McLeod gauge (*J*) serves to measure the pressure on the high-vacuum side. Taps *G* and *L* serve to isolate the various parts of the apparatus, which may be evacuated initially, *via* taps *L* and *F*, by the rotary oil-pump.

SAMPLING PROCEDURE

Liquid-Steel Sample

After thorough cleaning, with emery paper if necessary, and degreasing with carbon tetrachloride and ether, the sampling tubes are dried at 110° C. The sampling tubes are set up on the furnace stage and the ground joint in the sealed mould cap is lightly coated with a hard grease. A sample of metal is withdrawn from the furnace in a well-slagged spoon, the surface is skimmed, and the metal is immediately killed with aluminium wire. The requisite amount of metal is then poured into the sealed-mould tube (and into the chilled-pencil tube if this sample also is being taken). The pouring funnel is removed and the mould quickly closed by the steel cap (*D*, Fig. 5) ; the joint is clamped tightly and the sealed mould is then plunged into the running cold water until cool. The foregoing operations should not occupy more than 15 sec. The liquid-steel sample should be sufficient to occupy approximately one-third of the tube ; this gives an approximate sample weight of 250 g. If larger samples are inadvertently poured into the tube the grease on the ground joint may be partly decomposed. The more stable silicone greases have definite possibilities in this particular application.

The metal samples in the spoon are treated with aluminium only when necessary ; *e.g.*, electric-arc samples taken during the refining period are quite sound and no aluminium treatment is applied in such cases.

The water-chilled pencil sample, which weighs approximately 60 to 70 g., is withdrawn from the mould as soon as possible, and after removal of the upper scaled portion, is immediately stored under mercury in order to collect any gas that may be evolved during the waiting period until vacuum extraction is carried out. As will be seen later, for the results given in this report, this storing period has been extended up to 7 days for comparative purposes.

Extraction and Collection of Gases

The treatment of the sealed-mould sample for the extraction of its hydrogen may be described as follows :

Within the sealed mould the hydrogen exists in two fractions : (i) That contained in the sealed atmosphere above the metal sample, and (ii) that retained in the metal sample. Both portions are collected in the vacuum-extraction apparatus described previously.

The apparatus is evacuated and the ferro-manganese furnace heated to 850° C. in order to extract any hydrogen there may be in the ferro-manganese. This initial out-gassing may continue for several hours, or until a base pressure of less than 5×10^{-5} mm. of mercury is indicated by the McLeod gauge. The apparatus (Fig. 8) is then isolated from the oil-pump and a blank estimation is carried out for 1 hr. with the furnace (*C*) and the ferro-manganese furnace at 750° C. ; the blank is approximately 0·1 ml. of hydrogen per hour. The ferro-manganese tube is then isolated and air admitted into the furnace tube which is then detached at joint *B* ; the apparatus is now conditioned for the treatment of the metal samples.

The sealed mould is attached to the ground joint (*B*), and after evacuating to 5×10^{-5} mm., the vacuum tap, which closes the sealed mould, is slowly opened to allow the gases within the mould to pass through the apparatus. Pumping is continued until the base pressure is again restored, and the gases collected in the Toepler pump are swept out and removed for gas analysis. This gas sample, which may total 30 to 40 ml., consists of nitrogen and hydrogen, with traces of carbon monoxide and carbon dioxide. A typical analysis of this fraction is as follows :

$CO + CO_2$	0·2%
Hydrogen	14·4%
Nitrogen	85·4%

The nitrogen arises from air which is trapped within the sealed mould ; the oxygen is removed during passage over heated ferro-manganese.

The apparatus is now isolated at tap *G*, the sealed mould is detached, and the steel specimen is removed. After surface cleaning, if necessary, the specimen is washed in degreasing solvents, weighed, and introduced into the furnace tube *A*. The latter is attached to the joint *B* and evacuated initially by the oil-pump *via* tap *F*, then by the mercury-vapour pump to a base pressure of 5×10^{-5} mm. of mercury ; the apparatus is then isolated from the oil-pump at tap *L*. The heating furnace is moved into position over tube *A* and adjusted to maintain a temperature of 750° C. over the specimen. Evolution of hydrogen, after an initial heating-up period of about 10 min. is very rapid, and normally is complete after 45 min. although the heating is continued for 1 hr. The evolved gases are collected over mercury *via* the Toepler pump and are analysed for hydrogen by a modified Orsat type of apparatus described previously.[2] A typical gas analysis is as follows :

Oxygen, $CO + CO_2$	0·7%
Hydrogen	93·3%
Nitrogen	6·0%

The hydrogen content of the original liquid steel is

Table IV

HYDROGEN CONTENTS OF OPEN-HEARTH CASTS

Cast *N2244* was from an acid furnace, the remainder were from basic furnaces.

Cast No.	Time of Sampling	Approximate Composition at Time of Sampling, %	Hydrogen, ml./100 g.					
			Sealed Mould			Chilled Pencil		
			Evolved on Cooling	Extracted at 750° C.	Total	Evolved After 7 Days at Room Temp.	Extracted at 750° C.	Total
V5754	Tapping	0·6 C	1·9	4·5	6·4		3·5	
V5757	,,	0·35 C, 1·2 Mn, 0·4 Mo	2·9	4·4	7·3		2·6	
Z4680	,,	0·6 C, 1·0 Mn	2·3	4·3	6·6		3·8	
Z4683	,,	0·5 C, 1·0 Mn	4·6	1·3	5·9		3·2	
Z4694	,,	0·1 C, 3·1 Ni, 1·1 Cr	5·0	1·7	6·7		1·3	
Z4705	,,	0·3 C, 1·0 Mn, 0·3 Mo	0·8	5·2	6·0		5·5	
V5818	,,	0·3 C, 1·0 Mn, 0·3 Mo	6·7	2·9	9·6		1·9	
K1555	Melted	0·7 C, 0·7 Ni	2·0	2·6	4·6			
	Tapping	0·5 C, 1·0 Ni	3·3 2·9	6·0 5·5	9·3 8·4	1·7	3·2	4·9
K1593	Melted	0·7 C, 0·7 Ni	2·0 4·4	7·3 6·2	9·3 10·6	1·3	6·4	7·7
	Tapping	0·6 C, 0·5 Ni	3·8	8·0	11·8	2·0	5·3	7·3
Z5181	Melted	1·4 C, 0·4 Ni	3·1	1·1	4·2	0·2	1·1	1·3
	Tapping	0·4 C, 0·2 Ni, 0·2 Cr	3·4 2·9	4·8 4·8	8·2 7·7	2·0	1·8	3·8
Z5259	Melted	0·5 C, 0·8 Ni	3·0 3·5	5·3 4·3	8·3 7·8	1·4	3·3	4·7
	Tapping	0·08 C, 0·8 Ni	4·6 4·2	5·1 5·6	9·7 9·8	2·2	3·8	6·0
V6407	Melted	1·4 C, 0·4 Cr	1·5	6·1	7·6			
	Tapping	1·1 C, 0·5 Cr	2·3	5·8	8·1	1·5	4·7	6·2
V6441	Melted	0·7 C, 0·3 Ni, 0·4 Cr	2·3 2·7	4·7 4·1	7·0 6·8	1·6	3·8	5·4
	Tapping	0·4 C, 0·3 Ni, 0·2 Cr	3·3 4·0	5·6 5·8	8·9 9·8	2·5	2·6	5·1
K1761	Melted	0·6 C, 1·5 Ni	2·2	4·3	6·5			
	Tapping	0·2 C, 1·8 Ni				2·0	2·4	4·4
Average:	Melted		2·5	4·3	6·8	1·2	3·6	4·8
	Tapping		3·4	4·6	8·0	2·0	3·3	5·4
N2244	Melted	1·1 C	1·8	2·1	3·9	0·6	2·2	2·8
	Tapping	0·4 C, 1·7 Mn, 0·4 Mo	3·4 3·3	1·3 1·5	4·7 4·8	0·5	1·2	1·7

given by the sum of the two fractions obtained as already described.

The hydrogen remaining in the solid chilled-pencil sample is extracted as described in the foregoing paragraphs. When the extraction apparatus is not immediately available, the sample is stored under mercury, during which time a variable proportion of gas is evolved. The hydrogen content of liquid steel by means of the chilled-pencil sample is thus obtained in two fractions, that evolved on standing and that extracted subsequently by heating at 750° C. Typical analyses of these gas samples are as follows :

	Evolved at Room Temp. under Mercury	Extracted at 750° C.
Oxygen, CO, and CO_2, %	3	2
Hydrogen, %	90	90
Nitrogen, %	7	8

RESULTS OBTAINED

A selection of typical results obtained from open-hearth and electric-arc furnace baths is given in Tables IV to VII. Table IV relates to open-hearth casts of carbon and low-alloyed materials, mainly basic steels. The hydrogen content at tapping is given in every case and in some cases the hydrogen content at melted is available. There are also a number of duplicate sealed-mould determinations which illustrate the reproducibility of the hydrogen results. Table V refers to basic electric-arc casts which have been sampled at two stages, (*a*) in the refining period 10 min. after slag formation, and (*b*) shortly before tapping. In the case of the open-hearth samples vacuum-fusion determinations for oxygen, hydrogen, and nitrogen have been carried out on suitable pieces cut from the chilled-pencil sample, with the results given in Table VI. In Table VII are the results of vacuum-fusion determinations on the identical specimens after low-temperature extraction for hydrogen.

COMMENTS ON RESULTS

In general, the agreement between duplicate samples for hydrogen obtained by the sealed mould is good. The maximum difference between duplicates is 1·3 ml./100 g. at an average hydrogen content of 10 ml./100 g., and in most of the examples agreement is within 0·5 ml./100 g. The electric-arc casts show excellent agreement between duplicates, the maximum range being 0·7 ml. at 4·2 ml./100 g., whilst most of the duplicates are within 0·3 ml./100 g. The better agreement with electric-arc practice may be due to the greater ease of sampling or to the deoxidized-bath conditions. Since the duplicate samples were obtained from different spoonfuls of metal, it might be said that, at the stages under comparison, the electric-arc bath shows greater uniformity of hydrogen content than does the open-hearth bath.

Comparison of the hydrogen results given by the two sampling methods shows that the sealed-mould value is higher than the chilled-pencil value, the average difference in total hydrogen content by the two methods being of the order of 2·0 to 2·5 ml./100 g. This difference is entirely expected ; it is due to the loss of hydrogen during the cooling of the solid sample. In the open chilled-pencil sample, the hydrogen evolved during cooling is lost, whilst in the sealed mould it is retained within the mould and subsequently measured. The amount of hydrogen lost during cooling will depend on a number of factors, including rate of cooling, composition of steel in so far as this affects the hydrogen solubility, rate of hydrogen diffusion, and internal structure of the solid steel. Previous workers have reported on this difference in the results obtained from different types of sample. Comparing results by the balloon-tube and pencil-stick, mould-cooled samples, Newell[4] obtained considerable differences in hydrogen content, although the difference was less marked as the alloy content of the sample increased. Wells and Barraclough,[9] working mainly on alloy steels, including highly alloyed austenitic qualities, found less difference between the balloon-tube and pencil-stick samples and that a water-chilled sample (of larger dimensions than that of the present authors) agreed with the balloon-tube sample. They therefore modified the pencil-stick sampling method so that the sample was removed and quenched in water immediately after casting. In this way higher values were obtained. It should be remembered that these conclusions relate strictly to alloy steels and may not be equally applicable to the carbon and low-alloy types.

As further confirmation of the importance of alloy content in determining how closely the chilled-pencil test shall agree with the sealed-mould test, the results for the electric-arc steels given in Table V are interesting. The differences between the total hydrogen values for the two samples are, on the average, greater for the early refining-stage samples than for the tapping samples. The latter samples, which are of higher chromium content and generally of a higher hydrogen content, show greater retention of hydrogen in the solid sample. It is clear, therefore, that the open-tube type of sample will more closely reproduce the hydrogen content of the original liquid steel with highly alloyed steels.

On the chilled-pencil samples from the open-hearth casts, vacuum-fusion determinations, for oxygen content mainly, have been carried out. These are given in Table VI, together with the hydrogen and nitrogen values. It will be noted that the hydrogen values, which in any case are obtained with less precision than by the low-temperature extraction methods, bear little relation to either the sealed-mould or the chilled-pencil hydrogen results. This is not surprising in view of the varying time intervals between sampling and carrying out the vacuum-fusion determinations.

The vacuum-fusion test results given in Table VII are particularly interesting, as they were obtained on the identical specimens used for the chilled-pencil hydrogen determinations ; these specimens would therefore presumably be free from hydrogen. The hydrogen values obtained in these vacuum-fusion tests are insignificant, being within the nil or trace limits of the vacuum-fusion apparatus ; this is further confirmation that vacuum extraction at 750° C. is satisfactory for the determination of total hydrogen in solid steel, and that no additional hydrogen is obtained on extending the extraction up to 1650° C.

Comment on the metallurgical significance of the hydrogen results is not warranted for present purposes.

However, several general conclusions are apparent from the results in Tables IV and V :

(1) The hydrogen content of open-hearth steel at tapping is higher than at melted. The average increment between these two stages is of the order of 1·2 ml./100 g. This hydrogen increment may be related to changes consequent upon the refining of the liquid-steel bath, or it may be due to hydrogen introduced by finishing alloys, particularly ferromanganese. The latter cause is probably secondary to the changes in hydrogen that occur during refining ; other workers have reported that in basic practice there is usually a decrease in hydrogen content during early stages of boiling, followed by an increase to a final value higher than the initial.

(2) Hydrogen appears to increase slightly during the reducing period of the basic electric-arc process, the average increase being of the order of 0·9 ml./100 g. In this case, however, the increment may be related more directly to the alloy additions than is so with the open-hearth steels, as the larger increases are obtained with the higher-chromium casts.

(3) Comparing the different steelmaking processes, some broad generalizations are possible. The basic

Table V

HYDROGEN CONTENTS OF BASIC ELECTRIC-ARC CASTS

Cast No.	Time of Sampling	Analysis at Time of Sampling, %	Hydrogen Content, ml./100 g.					
			Sealed Mould			Chilled-Pencil Mould		
			Evolved on Cooling	Extracted at 750° C.	Total	Evolved in 7 Days at Room Temp.	Extracted at 750° C.	Total
H6742	10 min. after white slag	0·11 C, 0·49 Cr	2·6 3·1	2·5 2·0	5·1 5·1	2·2	0·5	2·7
	Just before tapping	0·18 C, 1·04 Cr	2·6 2·5	2·7 2·5	5·3 5·0	2·6	1·0	3·6
H6752	10 min. after white slag	0·87 C, 0·22 Cr	2·2 3·1	2·5 1·7	4·7 4·8	2·2	1·5	3·8
	Just before tapping	1·02 C, 1·45 Cr, 0·19 Al	1·4	3·8	5·2	0·8	3·7	4·5
H6774	10 min. after white slag	0·07 C, 0·47 Cr	4·7 5·2	1·5 1·0	6·2 6·2	2·7	0·5	3·2
	Just before tapping	0·25 C, 3·17 Cr, 0·52 Mo	3·0 2·8	4·8 5·5	7·8 8·3	4·1	2·8	6·9
H6789	10 min. after white slag	0·81 C, 0·25 Cr	2·1	3·0	5·1	1·8	1·5	3·3
	Just before tapping	1·03 C, 1·38 Cr	1·0	4·3	5·3	0·3	4·1	4·4
H6797	10 min. after white slag	0·10 C, 0·40 Cr	3·4	1·9	5·3	1·8	1·1	2·9
	Just before tapping	0·25 C, 3·21 Cr, 0·6 Mo	3·0 2·6	3·9 4·0	6·9 6·6	3·5	3·1	6·6
H6810	10 min. after white slag	1·3 C, 0·09 Cr	2·2 1·8	2·4 2·1	4·6 3·9	0·9	2·0	2·9
	Just before tapping	1·3 C, 0·21 Cr	1·6 1·5	2·8 3·0	4·4 4·5	0·3	2·8	3·1
H6818	10 min. after white slag	0·09 C, 0·38 Cr	3·0	3·0	6·0	2·7	0·8	3·5
	Just before tapping	0·10 C, 5·18 Cr, 0·54 Mo	3·1 2·7	4·4 4·6	7·5 7·3	5·0	1·0	6·0
Average:	After white slag		3·0	2·2	5·2	$2·0_5$	$1·1_5$	3·2
	Tapping		2·2	3·9	6·1	2·4	2·6	5·0

Table VI

VACUUM-FUSION DETERMINATIONS ON CHILLED-PENCIL SAMPLES

Cast *N*2244 was from an acid furnace, the remainder were from basic furnaces.

Cast No.	Time of Sampling	Analysis at Time of Sampling, %								Vacuum-Fusion		
		C	Mn	Si	S	P	Ni	Cr	Mo	O_2, %	H_2* ml./ 100 g.	N_2, %
*V*5754	Tapping	0·64	0·38	0·15	0·035	0·048	0·27	0·09	...	0·041 0·043†	4·0	$0·002_5$
*V*5757	Tapping	0·35	1·15	0·15	0·036	0·034	0·22	0·10	0·40	0·023 0·019†	3·5	0·002
*Z*4680	Tapping	0·58	0·98	0·40	0·036	0·038	0·22	0·10	...	0·022 0·021†	2·5	0·001
*Z*4683	Tapping	0·53	0·96	0·40	0·030	0·020	0·15	0·08	...	0·038	3·5	$0·001_5$
*Z*4694	Tapping	0·13	0·40	0·10	0·030	0·035	3·10	1·10	...	0·042	2·5	0·001
*Z*4705	Tapping	0·33	1·00	0·10	0·030	0·030	0·25	0·12	0·28	0·015	4·0	0·001
*V*5818	Tapping	0·28	1·05	0·08	0·035	0·026	0·27	0·22	0·28	0·020	1·0	0·001
*K*1555	Melted	0·68	0·22	...	0·075	0·40	0·72	0·11	...	$0·010_5$	2·0	$0·002_5$
	Tapping	0·48	0·57	0·07	0·043	0·050	0·98	0·11	...	0·024	0·7	0·001
*K*1593	Melted	0·66	0·28	...	0·075	0·30	0·67	0·19	...	$0·012_5$	1·0	0·001
	Tapping	0·56	0·50	0·07	0·038	0·038	0·47	0·19	...	$0·019_5$	0·4	0·001
*Z*5181	Melted	1·40	0·25	...	0·075	0·16	0·36	0·18	...	0·011	2·1	0·001
	Tapping	0·39	0·50	0·10	0·038	0·018	0·15	0·15	...	$0·024_5$	1·4	0·001
*Z*5259	Melted	0·54	0·25	...	0·045	0·10	0·80	0·22	...	0·024	6·8	$0·006_5$
	Tapping	0·08	0·17	Trace	0·034	0·027	0·80	0·10	...	$0·059_5$	3·1	0·002
*N*2244	Melted	1·06	0·07	...	0·039	0·043	0·29	0·09	...	$0·012_5$	2·8	0·002
	Tapping	0·37	1·70	0·11	0·041	0·043	0·29	0·09	0·42	$0·045_5$	2·8	$0·002_5$
*V*6407	Melted	1·43	0·53	...	0·052	0·40	0·17	0·39	...	Sample unsatisfactory		
	Tapping	1·05	0·43	0·10	0·028	0·030	0·19	0·50	...	,,		,,
*V*6441	Melted	0·74	0·32	...	0·075	0·25	0·27	0·37	...	0·012	4·5	$0·002_5$
	Tapping	0·35	0·40	0·10	0·045	0·020	0·27	0·18	...	0·041	4·6	$0·002_5$
*K*1761	Melted	0·56	0·26	...	0·075	0·15	1·50	0·27	...	0·021	4·8	0·003
	Tapping	0·20	0·38	0·10	0·040	0·010	1·84	0·23	...	0·035	5·1	0·001

* Residual hydrogen contents of the samples, no account being taken of loss during storage.
† Duplicate vacuum-fusion determinations were carried out on sealed-mould samples.

Table VII

VACUUM-FUSION DETERMINATIONS ON CHILLED-PENCIL SAMPLES (BASIC ELECTRIC-ARC CASTS)

Cast No.	Time of Sampling	Analysis at Time of Sampling, %									Vacuum-Fusion		
		C	Mn	Si	S	P	Ni	Cr	Mo	Al	O_2, %	H_2,* ml./100 g.	N_2, %
H6742	10 min. after white slag	0·11	0·28	0·15	0·044	..	..	0·49	..	..	0·017$_5$	0·1	0·004$_5$
	Just before tapping	0·18	0·45	0·20	0·025	0·027	0·20	1·04	..	..	0·007	0·1	0·006
H6752	10 min. after white slag	0·87	0·18	0·15	0·026	..	..	0·22	..	..	..	..	..
	Just before tapping	1·02	0·38	0·34	0·014	0·019	0·11	1·45	..	0·19	..	..	..
H6774	10 min. after white slag	0·07	0·26	0·15	0·028	..	..	0·47	..	..	0·016	0·1	0·006
	Just before tapping	0·25	0·56	0·23	0·016	0·020	0·22	3·17	0·52	..	0·012 0·011†	<0·1 0·1	0·007 0·008
H6789	10 min. after white slag	0·81	0·20	0·15	0·033	..	..	0·25	..	..	..	..	..
	Just before tapping	1·03	0·37	0·28	0·018	0·015	0·10	1·38	..	..	..	..	..
H6797	10 min. after white slag	0·10	0·17	0·15	0·034	..	..	0·40	..	..	..	..	..
	Just before tapping	0·25	0·54	0·19	0·015	0·019	0·14	3·21	0·60	..	..	..	..
H6810	10 min. after white slag	1·30	0·32	0·15	0·033	..	..	0·09	..	..	0·002$_5$†	0·2	0·005$_5$
	Just before tapping	1·30	0·33	0·17	0·010	0·022	0·10	0·21	..	..	0·003	<0·1	0·004$_5$
H6818	10 min. after white slag	0·09	0·11	0·15	0·050	..	..	0·38	..	..	0·034	·2	0·007
	Just before tapping	0·10	0·42	0·40	..	..	..	5·18	0·54	..	0·014$_5$	0·2	0·007$_5$

* Residual hydrogen contents after vacuum heating.
† Duplicate vacuum-fusion determinations carried out on sealed-mould samples.

open-hearth casts have an average hydrogen content at tapping of 8·0 ml./100 g. As most of these samples are very low-alloyed types it is not possible to break down the results further according to metal composition. The basic electric-arc casts have an average hydrogen content at tapping of 6·1 ml./100 g.; those casts with less than 3% of chromium show hydrogen contents below the average, while those with more than 3% of chromium have greater than average hydrogen contents. Only one acid open-hearth cast is reported, but it is interesting to note that this contains 4·7 to 4·8 ml. of hydrogen per 100 g. at tapping. The significance of these differences between the steelmaking processes might well be of some interest in the study of hair-line crack formation.

CONCLUSIONS

The sealed-mould sampling method, as described in this paper, provides a satisfactory method for the determination of hydrogen in liquid steel. With suitable laboratory arrangements the determination may be completed within 2 to 2½ hr., including full gas analysis, whilst indications of the hydrogen content may be obtained within 1 hr. of sampling. The immediate practical value of this method would seem to be in providing a means of indicating those casts which, on account of a high hydrogen content, would require special treatment during processing. Its application to the fundamental study of steelmaking processes is apparent.

The chilled-pencil test also has possibilities. It enables the hydrogen figure to be obtained within 1 hr. and, provided that its limitations in respect to hydrogen content are appreciated, and these are not unduly large with the higher-alloy steels, this form of sample is also very suitable for a combined rapid oxygen and hydrogen determination.

Both methods will therefore have very useful applications in many problems of ferrous metallurgy.

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(*A list of references is given on the next page.*)

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Part IV—A Co-operative Examination of a Manganese–Molybdenum Steel

By T. E. Rooney, A.M.C.T., F.R.I.C.

SYNOPSIS

Results are presented of micrographic examination and oxygen determinations by vacuum fusion, fractional vacuum fusion, aluminium reduction, and the chlorine and alcoholic iodine residue methods, of a manganese–molybdenum steel. The presence of rhodonite and tephroite and possibly of a small amount of manganese anorthite in an acid-extracted residue is indicated by X-ray examination.

THIS paper presents the results of an investigation of the applicability to a commercial low-alloy steel of the methods of examination of non-metallic inclusions developed by the members of the Gases and Non-Metallics Sub-Committee.

The co-operators taking part in the investigation were:

S. W. CRAVEN	I.C.I. (Alkali), Ltd., Northwich
R. E. LISMER	United Steel Companies, Ltd.
H. MORROGH	British Cast Iron Research Association
G. MURFITT	Wm. Jessop and Sons, Ltd.
M. C. SANDERS	Steel Company of Wales, Ltd., Port Talbot
R. J. SARJANT	Hadfields, Ltd.
C. W. SHORT	J. Lysaght, Ltd., Scunthorpe
G. E. SPEIGHT	United Steel Companies, Ltd.
H. A. SLOMAN	National Physical Laboratory
J. E. WELLS	Steel Company of Wales, Ltd. (formerly of Brown-Firth Research Laboratories)
J. H. WHITELEY	Consett Iron Co., Ltd.
T. H. WILLIAMS	Stewarts and Lloyds, Ltd., Corby

Mr. F. TRANTER, of A.I.D., Ministry of Supply, Harefield, also collaborated in the work.

The steel chosen for the work has a relatively high oxygen content (0·025%), which is a desirable feature particularly with regard to examination by the residue methods. In previous work on alloy steels of low oxygen contents (0·005%) the limits of accuracy of the methods and the refractory nature of the steels presented a very difficult problem in determining the proportions of a number of constituents in so low a total.

Details of Cast *F*430

The steel was supplied by Messrs. Colvilles, Ltd., and details of the cast, No. *F*430, basic open-hearth, are as follows:

Cast Analysis, %

Carbon	0·21	Phosphorus	0·026
Silicon	0·14	Nickel	0·60
Manganese	1·38	Chromium	0·12
Sulphur	0·026	Molybdenum	0·26

Charge, tons

Pig iron	22·65
Scrap	18·20
Alloy scrap	28·60
Lime	3·18
Scale	1·00

Bath Additions, cwt.

Molybdenum bricks	2
Ferro-molybdenum	¾
Nickel	1

Ladle Additions, cwt.

Ferro-silicon	5½
Ferro-manganese	28

Yield

32 ingots at 43 cwt. (Tiled, top-wide, end-up, square mould)

Preparation of Samples

The material was rolled to 3¼-in. dia. and rough-turned to 3-in. dia. An 8½-in. length of 3-in. dia. bar from the top of the bottom billet of ingot No. 14 was rolled to ½-in. dia. and cut into 1-ft. lengths marked consecutively 1, 2, 3, etc.

MICROSCOPICAL EXAMINATION

Report by Dr. J. H. Whiteley

The inclusions in the steel appeared to be of two kinds, *viz.*, manganese sulphide (MnS), of which there was only a small amount, and silicates. The latter were fairly evenly distributed, although a few stringers of the type illustrated in Fig. 9 occurred. Part of the same inclusion under a higher magnification is seen in Fig. 10, which shows its glassy nature. A very striking feature of these inclusions, as seen in the longitudinal section, was that many of them showed diffraction lines under the ⅛-in. (4-mm.)

Paper SM/BB/99/48 of the Gases and Non-Metallics Sub-Committee of the Ingots Committee of the Steel-making Division of the British Iron and Steel Research Association, received 23rd September, 1948.

Mr. Rooney is at the National Physical Laboratory, Teddington.

objective, as shown in Fig. 11. After boiling the specimen for 30 min. in 25% caustic soda solution, it was found that the silicates were partly dissolved. The attack seemed to be confined to those portions giving diffraction lines, for in many cases dark idiomorphic crystals remained in the cavities. An example is given in Fig. 12. After another boiling in sodium hydrate for 30 min., no further change was apparent. The two crystals were still of the same shape and size. The area shown in Fig. 11, after the above treatment, is shown in Fig. 13. In it there are two narrow dark inclusions which were quite unattacked, so that they are apparently of the same nature as the idiomorphic crystals in Fig. 12. Holding the specimen for 1 min. in hydrofluoric acid sufficed to dissolve these crystals (*see* Fig. 14), and it may thus be inferred that they are silicates and not alumina, Al_2O_3. It is concluded, therefore, that the oxygen-bearing inclusions consist of silicate crystals often embedded in a glass. They are more frequently to be seen without the glass in the cross-section. An example is given in Fig. 15. A 2-min. etch in hydrofluoric acid seemed to remove them completely.

Report by Mr. H. Morrogh

From the point of view of inclusion examination, under polarized light, the sample is comparatively uninteresting. The minor phases present were of either manganese sulphide or a silicate phase, the composition of which is not known. Under polarized light, the manganese sulphide showed a green coloration which persisted for all positions of the stage, and the silicate phase showed a white coloration which again persisted for all positions of the stage. This is usual for manganese sulphide and, as far as the silicate phase is concerned, it indicates it to be optically isotropic, that is, either cubic or glassy. The silicate, whilst appearing black or dark grey under vertical illumination, must be partially transparent to white light. This was further confirmed by the appearance of some of the silicates on the micrographs. From previous experience it is suggested that the silicate phases are manganese–iron silicate.

Most of the micrographs were taken from the longitudinal section, but three were taken from the transverse section. The apparent size of the particles varied considerably. Frequently, the sulphide and silicate phases occurred together. Particularly when the sulphide was obviously elongated, did the silicate phase appear to be attached at either end. This is illustrated in Figs. 16, 17, and 18. The translucency of the silicate phase is illustrated in Figs. 19 and 20 and is indicated by the lighter appearance of certain patches of the inclusion. Figure 21 shows a silicate particle which has been cut by the polished surface so that it is thick at one side and thin at the other. The obvious translucency of the phase can be seen. The translucency of the sulphide phase is illustrated particularly in Figs. 18 and 21, where bright areas inside the sulphide can be seen, together with interference fringes. This is characteristic of manganese sulphide.

These various points are illustrated several times in Figs. 16 to 30, which have all been taken at a magnification of 1500 and are all unetched.

Report by Mr. R. E. Lismer

The following types of inclusions were identified in the steel :

(1) Angular, often massive, silicates. These were crystalline and very poorly malleable and showed a tendency to occur in segregates, mainly towards the centre of the section. Under polarized illumination these silicates appeared whitish-blue or green in colour, indicating the presence of alumina.

(2) Slightly darker silicate streaks. These were less crystalline than type (1), appeared very malleable, and showed only a slight tendency to segregate, generally occurring isolated. Under polarized illumination the streaks appeared darkish-red, and it is suggested that these do not contain alumina, that they are of a lower silica content than type (1), and that the main constituent is manganese oxide (MnO).

(3) Other oxides and silicate particles associated with elongated sulphides.

(4) Elongated manganese sulphides, generally small in size, and tending to be absent in areas containing silicate segregates.

A few inclusions of a duplex nature, consisting partially of type (1) and partially of type (2), were present. When the specimen was etched for 2 min. in 2% hydrochloric acid in alcohol, the two types of silicate behaved differently. There was no effect on the angular type (1) (Fig. 31), but the malleable type (2) showed evidence of attack by the acid on the centre portions of the streaks (Fig. 32).

INCLUSION COUNTS

In order to determine the distribution of oxide and sulphide types of inclusions, counts were carried out on a specimen taken from the 3-in. square billet. The specimen was divided into three zones : Surface to a depth of ½ in., ½ in. to a depth of 1 in., and 1 in. to centre of billet. In each of these zones three strips 0·010 in. wide and ½ in. in length were randomly chosen, and every inclusion not less than 0·0001 in. in length was counted both individually and with respect to its length. The latter was measured to the nearest 0·0001 in., and the following results are expressed as the 'total length' of the inclusions present within the three strips or an area of 0·015 sq. in. The counts were made at a magnification of 720.

Zone	Oxides and Silicates		Sulphides	
	Number	Total Length, in.	Number	Total Length, in.
Surface to ½ in.	71	0·0472	264	0·1357
½ to 1 in. deep	305	0·2368	163	0·1060
1 in. to centre	413	0·3544	259	0·1158

The values show the predominance of silicate inclusions, with segregation of silicates towards the centre, and a preponderance of sulphides towards the surface of the billet. A sulphur print confirmed the distribution of the sulphides.

Microscopic examination has also been carried out by the Research Department of Messrs. Hadfields, Ltd., the Brown-Firth Research Laboratories, and the Aeronautical Inspection Directorate, and the results are in agreement with those reported above.

SUMMARY

Detailed microscopical examination of the non-metallic inclusions present in specimens taken from cast *F*430, a manganese–molybdenum steel manufactured in the basic open hearth by Messrs. Colvilles, Ltd., has revealed the following features :

Table VIII

OXIDE AND OXYGEN DETERMINATIONS BY THE RESIDUE AND VACUUM-FUSION METHODS

The ratio MnO/SiO_2 for a mixture of equal parts of rhodonite and tephroite = 1·78.
The values for SiO_2, FeO, etc., given for the fractional vacuum-fusion method are obtained by calculation from the amounts of CO extracted at certain temperatures.
The iodine and chlorine residues also contain small amounts of P_2O_5 and Cr_2O_3.

Laboratory	Method	Bar No. and Dia. of Sample	Oxide and Oxygen as Percentage of Metal								(MnFe)O/SiO_2	Total Oxygen, %	
			SiO_2		FeO		Al_2O_3		MnO				
			Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen		Calculated	Direct
N.P.L.	Alcoholic iodine	(8) (end *b*) 11 mm.	0·028	0·015	0·009	0·002	0·003	0·001	0·043	0·010	1·86	0·028	
		(8) 11 mm.	0·028	0·015	0·011	0·002	0·003	0·001	0·039	0·009	1·79	0·027	
	Vacuum fusion	(8) (end *a*) 11 mm.	..	..	..	..	..	..	..	..	..	..	0·026
		(8) (end *b*) 11 mm.	..	..	..	..	..	..	..	..	..	..	0·027
		(6) 11 mm.	..	..	..	..	..	..	..	..	..	..	0·022
United Steel Cos., Ltd.	Fractional vacuum fusion	(3) 10 mm.	0·026$_5$	0·014	0·002	0·000$_5$	0·009$_5$	0·004$_5$	0·024	0·005$_5$	0·98	0·024$_5$	
	Vacuum fusion	(3) (end *a*) 10 mm.	..	..	..	..	..	..	..	..	..	..	{0·023
		(3) (end *b*) 10 mm.	..	..	..	..	..	..	..	..	..	..	{0·022$_5$ 0·023$_5$
J. Lysaght, Ltd.	Chlorine												
	350° C.	(11) $\frac{7}{16}$ in.	0·023	0·012	0·009	0·002	0·005	0·002	0·020	0·004$_5$	1·26	0·020$_5$	
	450° C.	(11) $\frac{7}{16}$ in.	0·025	0·013	0·009	0·002	0·005	0·002	0·016	0·003$_5$	1·00	0·020$_5$	
	500° C.	(11) $\frac{7}{16}$ in.	0·023	0·012	0·008	0·002	0·004	0·002	0·021	0·005	1·26	0·021	
	450° C.	(8) $\frac{7}{16}$ in.	0·028	0·015	0·009	0·002	0·003	0·001	0·026	0·006	1·25	0·024	
	450° C.	(8) $\frac{7}{16}$ in.	0·020	0·011	0·012	0·003	0·005	0·002	0·022	0·005	1·70	0·021	
Stewarts and Lloyds, Ltd.	Chlorine, 350° C.	(12) $\frac{7}{16}$ in.	0·025	0·013	0·005	0·001	0·005	0·002	0·016	0·004	0·86	0·020	
I.C.I., Ltd.	Chlorine, 350° C.	(1) $\frac{7}{16}$ in.	0·026$_5$	0·014	0·009	0·002	0·006	0·003	0·015	0·003	0·91	0·022	
Guest Keen Baldwins	Aluminium reduction	(9) (end *a*) 10 mm.	..	..	..	..	..	..	..	..	..	..	0·022
		(9) (middle) 10 mm.	..	..	..	..	..	..	..	..	..	..	0·022
		(9) (end *b*) 10 mm.	..	..	..	..	..	..	..	..	..	..	0·024
A.I.D.	Aluminium reduction	(9)	..	..	..	..	..	..	..	..	..	..	0·022
Brown-Firth	Vacuum fusion	(6) $\frac{1}{2}$ in.	..	..	..	..	..	..	..	..	..	..	0·019
		(6) (10 mm.) $\frac{3}{8}$ in.	..	..	..	..	..	..	..	..	..	..	0·021
		(8) $\frac{1}{2}$ in.	..	..	..	..	..	..	..	..	..	..	0·023
		(8) 11 mm.	..	..	..	..	..	..	..	..	..	..	0·025

Fig. 9 × 75

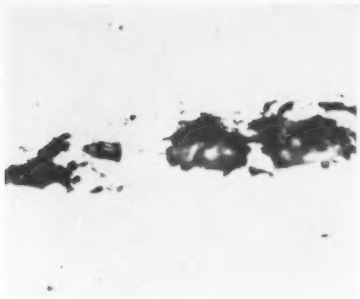

Fig. 10 × 520

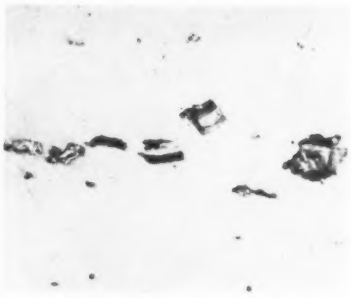

Fig. 11 × 520

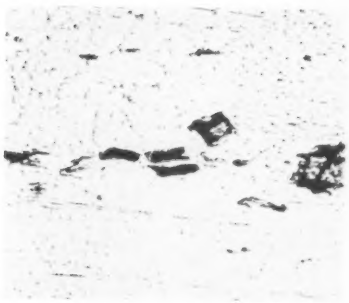

Fig. 12 × 520

Fig. 13 × 520

Fig. 14 × 520

Fig. 15 × 520

Figs. 9 to 15—Photomicrographs of steel F 430, from the Consett Iron Co., Ltd.

Fig. 16

Fig. 17

Fig. 18

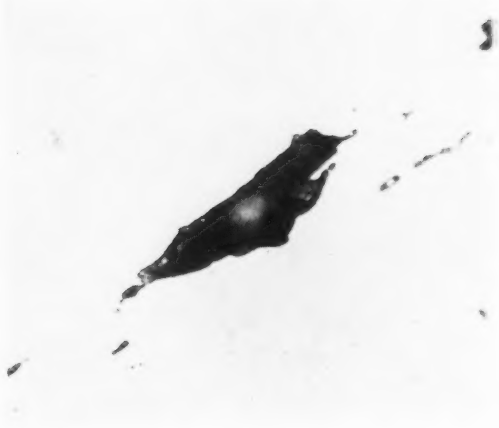

Fig. 19

Fig. 20

Fig. 21

Figs. 16 to 21—Photomicrographs of longitudinal sections (unetched) of steel F 430, from the British Cast Iron Research Association × 1500

Fig. 22

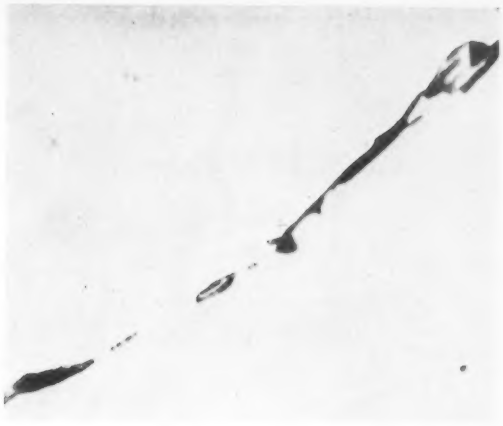

Fig. 23

Fig. 24

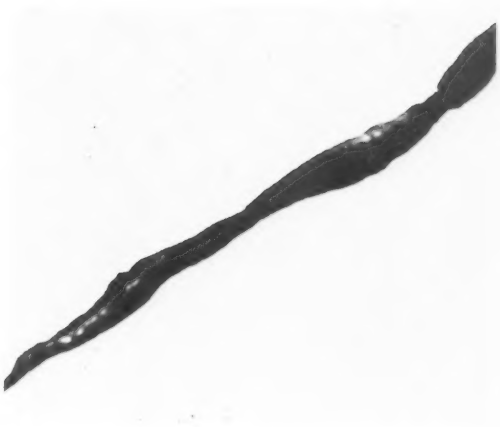

Fig. 25

Fig. 26

Fig. 27

Figs. 22 to 27—Photomicrographs of longitudinal sections (unetched) of steel F 430, from the British Cast Iron Research Association × 1500

Fig. 28

Fig. 29

Fig. 30

Figs. 28 to 30—Photomicrographs of transverse sections (unetched) of steel F 430, from the British Cast Iron Research Association × 1500

Fig. 31

Fig. 32

Figs. 31 and 32—Photomicrographs of steel F 430, etched with 2 % hydrochloric acid, from the United Steel Companies, Ltd., Research and Development Department × 800

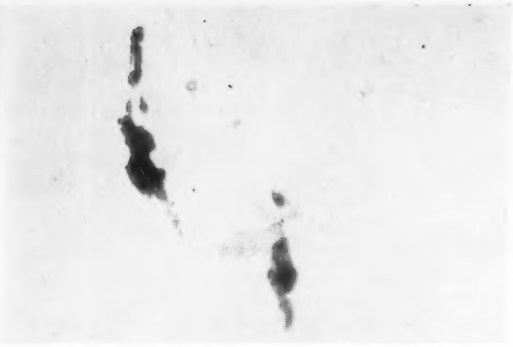

Fig. 33

Fig. 34

Fig. 35

Figs. 33 to 35—Photomicrographs of steel X 598 (unetched), from the Brown-Firth Research Laboratories × 800

Fig. 36—Photomicrograph of steel X 598 (unetched), from the United Steel Companies, Ltd., Research and Development Department × 1000

Fig. 37—G11, duplex silicate sulphides × 800

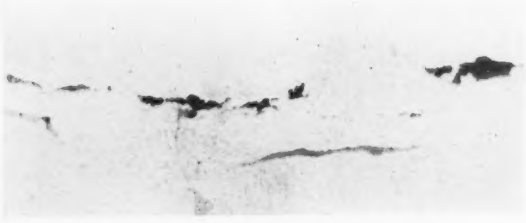

Fig. 38—G11, silicate streaks and elongated sulphides × 800

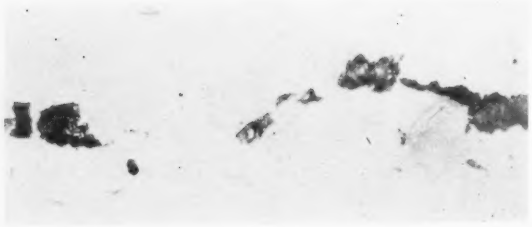

Fig. 39—H11, silicate streak × 800

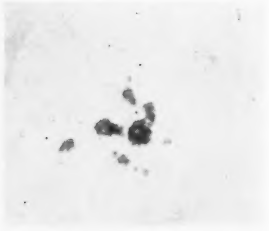

Fig. 40—H11, alumina particles × 1200

Figs. 37 to 40—Photomicrographs of steel G 9761

(1) The predominating type of inclusions consisted of silicates, occurring as streaks or stringers and increasing in size and concentration towards the centre of the bar. These inclusions contained dark idiomorphic crystals, often embedded in an amorphous material identified as glass. They were angular, often massive, and very poorly malleable.

(2) A second type of silicate streak which appeared darker, less crystalline and very malleable. These were attacked by 2% hydrochloric acid etching solution and are probably mainly MnO.

(3) Elongated manganese sulphide phase which showed translucency, together with interference fringes. These inclusions were of smaller size than the silicates and increased slightly in concentration towards the outer regions of the specimens.

(4) Frequent occurrence of duplex sulphide and silicate phases.

OXYGEN DETERMINATIONS

Total oxygen has been determined by the vacuum-fusion and aluminium-reduction methods. The oxides have been determined by fractional vacuum-fusion, the alcoholic iodine, and the chlorine methods. The results are given in Table VIII.

The total oxygen determined by the direct method varies from 0·019 to 0·027%. The values were checked by an exchange of samples between the National Physical Laboratory and the Brown-Firth Research Laboratories. The results are given below :

Variation of Total Oxygen by Vacuum Fusion, According to the Position and Diameter of the Sample

Bar No.	Dia. of Sample	N.P.L. Total Oxygen, %	Brown-Firth Total Oxygen, %
8	11 mm.	0·026, 0·027	0·025
8	½ in.	...	0·023
6	½ in.	...	0·019
6	⅜ in. (10 mm.)	...	0·021
6	11 mm.	0·022	...

(The ½-in. dia. bar could not be used in the N.P.L. apparatus.)

These results indicate that there is some segregation of oxygen along the length of the bar and also from the outside to the centre on the cross-section.

The total oxygen calculated by the fractional vacuum-fusion and the residue methods varies from 0·021 to 0·028% (Table VIII). It can be inferred from the results obtained by these methods that the inclusions are mainly silicates with manganese silicate predominating.

The highest MnO value is obtained by the alcoholic iodine method, but this may be accounted for to some extent by the fact that the sample used contained a higher percentage of oxygen than the samples used in the other methods. A check test on the same sample (bar 8) by the chlorine method yielded slightly higher values for MnO than those obtained on bar 11, but these values were well below those obtained by the iodine method. In Table VIII the ratio of (MnFe)O to SiO_2 is given for the fractional vacuum-fusion and residue methods. The ratio of MnO to SiO_2 for equal parts of rhodonite and tephroite is 1·78 : 1, and this value agrees with the corresponding value obtained by the alcoholic iodine method. There thus appears to be a fundamental difference between the two methods in this particular respect.

X-RAY EXAMINATION OF ACID-EXTRACTED RESIDUE

An examination by a modification of the Dickenson (acid-extraction) method has been carried out at the laboratory of Messrs. Wm. Jessop and Sons, Ltd. X-ray examination of the residue indicated the presence of about equal portions of rhodonite ($MnO.SiO_2$) and tephroite ($2MnO.SiO_2$) and possibly a small amount of manganese anorthite ($MnO.Al_2O_3.2SiO_2$). Amorphous material was also present. The absorption of cobalt radiation suggests that the residue is rich in manganese.

DISCUSSION

This work represents a preliminary attempt to correlate the results of the various methods of investigation which are available for the examination of non-metallic inclusions. The original objective was limited mainly to the determination of oxide inclusions, but the addition of microscopical examination has directed attention to the importance of sulphide inclusions and this in turn has led to some consideration of the inclusion counts. Such recent enlargement of the original objective must necessarily be of a tentative nature, but is useful in suggesting lines of research which may be a desirable feature in the future work of the Gases and Non-Metallics Sub-Committee.

SUMMARY OF RESULTS

The results of the microscopical examination and those of the residue methods and X-ray examination show that the principal oxide inclusions are two types of silicate, *viz.*, rhodonite and tephroite. In addition manganese sulphide is also present.

The total oxygen determinations indicate that there is segregation of oxygen along the length of the bar and possibly also from outside to centre on the cross-section. These conclusions are supported by the microscopical examination and the inclusion counts of the segregation of sulphides which suggests that in future work chemical determination of the sulphide might yield useful information.

In the oxide determinations the agreements between the results for silica (SiO_2) and for ferrous oxide (FeO) are good with the exception of the fractional vacuum-fusion value for FeO. Again with the exception of the fractional vacuum fusion the agreement between the values for alumina (Al_2O_3) is reasonable. The main disagreement is between the values for manganese oxide (MnO) by the iodine and chlorine methods.

To some extent the difference in the values may be accounted for by the higher oxygen content of the bar used for the iodine-method determinations, but, as noted above, it is considered that there is a fundamental difference in this respect between the two methods.

Some attempts have been made to solve this problem, but owing to shortage of samples and the evidence of segregation the present steel was not considered suitable for a continued investigation.

Part V—A Co-operative Examination of a Nickel–Chromium Steel

By T. E. Rooney, A.M.C.T., F.R.I.C.

SYNOPSIS

Results are presented of micrographic examination and oxygen determinations by vacuum fusion, fractional vacuum fusion, aluminium reduction and the chlorine and alcoholic iodine residue methods, of a nickel–chromium steel. The presence of α-quartz and manganese sulphide in an alcoholic iodine residue and of quartz and a pyroxene of rhodonite type in an acid-extracted residue, was indicated by X-ray examination.

THIS paper presents the results of an investigation of the applicability to alloy steels of the methods of examination of non-metallic inclusions developed for plain carbon steels by the Gases and Non-Metallics Sub-Committee. It proved difficult to find an industrial alloy steel of this type which had a sufficiently high oxygen content to be suitable for preliminary work, and a small laboratory ingot of low-carbon, 3% nickel, 0·6% chromium steel, was therefore kindly made up by I.C.I. (Alkali), Ltd. The sample is not representative of industrial steel. In order to simplify the problem, aluminium was not used for de-oxidation purposes.

The co-operators taking part in the investigation were as follows :

R. E. LISMER	United Steel Companies, Ltd.
I. M. MACKENZIE	Colvilles, Ltd.
D. MARLES	British Cast Iron Research Association
G. MURFITT	Wm. Jessop and Sons, Ltd.
T. E. ROONEY	National Physical Laboratory
M. C. SANDERS	Steel Company of Wales, Ltd., Port Talbot
R. J. SARJANT	Hadfields, Ltd.
C. W. SHORT	J. Lysaght, Ltd., Scunthorpe
G. E. SPEIGHT	United Steel Companies, Ltd.
H. A. SLOMAN	National Physical Laboratory
J. E. WELLS	Steel Company of Wales, Ltd. (formerly of Brown-Firth Research Laboratories)
J. H. WHITELEY	Consett Iron Co., Ltd.
T. H. WILLIAMS	Stewarts and Lloyds, Ltd., Corby

DETAILS OF PREPARATION (CAST *X*598)

The steel was made in a laboratory high-frequency induction furnace, melting being carried out in a Δ V5 sillimanite crucible. The total weight of material charged to the furnace was 15 lb., of which 10 oz. consisted of good quality mild steel, pieces of pure nickel plate (as distinct from nickel shot), and ferro-chromium. The melt was killed with small additions of ferro-silicon and electrolytic manganese, and no additions of aluminium were made to the bath. The metal was poured into a cast-iron mould, the surface of which had been coated with colloidal graphite.

The ingot as cast weighed 15 lb. 5 oz. It was cooled slowly in sand, skimmed in a lathe to produce a smooth surface, and then forged to approximately ½-in. dia. bar. The bar was cut up into 1-ft. lengths which were numbered from 1 to 15, starting at the bottom of the ingot. No. 15 contained the pipe and was retained by the I.C.I. Laboratory.

Paper SM/BB/97/48 of the Gases and Non-Metallics Sub-Committee of the Ingots Committee of the Steel-making Division of the British Iron and Steel Research Association, received 23rd September, 1948.

ANALYSIS

The steel was analysed by the Research and Development Department of the United Steel Companies, Ltd. The results are as follows :

Carbon, %	0·065
Manganese, %	0·32
Silicon, %	0·04
Sulphur, %	0·036
Phosphorus, %	0·017
Nickel, %	3·01
Chromium, %	0·66
Total aluminium, %	0·007
Aluminium as Al_2O_3 (gravimetric)	0·007
„ „ „ (colorimetric)	0·006

The aluminium was determined by other laboratories as follows :

British Cast Iron Research Association—The ½-in. bar was milled along its lengthwise axis and sparked at 26 points on the flat surface obtained. No aluminium was detected in any of the spark records. Previous experience has suggested that the aluminium would have to be less than 0·005% to remain undetected. By chemical methods the aluminium in the residue from acid solution was found to be less than 0·002%.

Colvilles, Ltd.—Results by colorimetric determination were :

Acid-soluble aluminium, %	0·001
Aluminium in residue from acid solution, %	0·004
Total aluminium, %	0·004

MICROSCOPIC EXAMINATION

Reports of microscopic examination from six laboratories are as follows :

Consett Iron Co., Ltd. Bar No. 9

The inclusions in this steel were not easy to identify. For the most part they were very small, which increased the difficulty of determining their nature. Only a few fine threads of manganese sulphide were to be seen, and the sulphur content was judged accordingly to be about 0·01%. At least four kinds of other non-metallics were present, *viz.* :

(1) Light glassy spherules and streaks.

(2) Dark opaque particles unattacked after boiling for 30 min. in 25% caustic soda solution.

(3) Dark and more vitreous inclusions which were attacked by boiling for 30 min. in 25% caustic soda.

(4) A few very heavy particles complex in character.

Some of the glassy particles were definitely insoluble in strong hydrofluoric acid (2-min. immersion). Many were so small that it was difficult to ascertain whether they had been attacked or not.

One or two glassy stringers were seen. The light glassy part of such inclusions was insoluble both in caustic soda solution and in hydrofluoric acid. The darker part, however, seemed to be attacked by hydrofluoric acid.

The fact that some particles were insoluble in hydrofluoric acid suggests that they may have been alumina (Al_2O_3), but glassy silica (SiO_2) particles (or silicate) may also have been present.

United Steel Companies, Ltd., Research and Development Department. Bar No. 3

The steel was fairly dirty, the inclusions being mainly randomly distributed, although a slight central segregation was evident. The following types were identified :

(1) Generally small and isolated dark silicate streaks (Fig. 33) which appeared darkish-red or brown under polarized light. This type of inclusion was fairly malleable. It was not attacked by 2% hydrochloric acid in alcohol, but completely attacked by ½% hydrofluoric acid. It is suggested that these streaks are mainly manganese silicate.

(2) Occasional larger stringers of idiomorphic crystals (Fig. 34) which appeared whitish under polarized light. These crystals were often associated with the more malleable type (1). They were unattacked by 2% hydrochloric acid and only very slightly attacked by hydrofluoric acid. It is suggested that the angular crystals are mainly aluminium silicate.

(3) Alumina as isolated particles, small stringers and larger stringers associated with some silicate (Fig. 35). These particles and stringers were not attacked by either hydrochloric or hydrofluoric acids.

(4) Many minute silica particles, fewer and smaller in size than the alumina particles. The silica particles were readily attacked by hydrofluoric acid.

(5) A few small elongated manganese sulphide inclusions.

Wm. Jessop and Sons, Ltd. Bar No. 10

Considerable numbers of non-metallic inclusions were observed. These were principally large elongated silicates, many containing a high proportion of silica. Small amounts of the following inclusion types were also noted.

(1) Small sulphide inclusions, sometimes associated with silica particles.

(2) Occasional very small silica particles.

Some oxide penetration adjacent to the bar surface was observed. An inclusion count, consisting of three traverses across the specimen each of 20 fields, gave the inclusion number as 89½.

Brown-Firth Research Laboratories. Bar No. 12

The inclusions consisted mainly of silicates with a few drawn-out sulphides, often duplex. Many of the silicates contained hard nodules, possibly aluminous, which gave rise to very irregular outlines as illustrated in Fig. 36 taken on a longitudinal section.

Hadfields, Ltd. Bar No. 5

The inclusions present were randomly distributed and fairly numerous. They consisted chiefly of silicate streaks, the longest of which was 0·019 in. in length, and of shorter fine threads of sulphide. Occasional very small globular inclusions of silica were present, associated with the silicate and sulphide inclusions.

British Cast Iron Research Association. Bar No. 2

The inclusions consisted of a small amount of manganese sulphide and some fairly large streaks of the iron–manganese silicate type. Other inclusions present appeared to be manganese oxide and possibly some silica, although this was very difficult to assert definitely as the inclusions were extremely small.

SUMMARY OF THE REPORTS OF MICROSCOPICAL EXAMINATION

The steel was fairly dirty, the inclusions being mainly very small and randomly distributed.

The main type of inclusion consisted of silicate distributed irregularly as small streaks or broken stringers, but occasionally fairly large. These were attacked by hydrofluoric acid and unattacked by a solution of caustic soda (25%). Other silicates were darker and vitreous in nature and only slightly attacked by hydrofluoric acid. It is probable that these inclusions are of the manganese silicate type, some in combination with alumina as manganese aluminium silicate or even mainly aluminium silicate.

Other inclusions observed consisted of particles and small stringers of alumina, minute glassy silica particles, and a few fine threads of manganese sulphide.

OXYGEN DETERMINATIONS

The results of the oxygen determinations from six laboratories are given in Table IX. The agreement between the total-oxygen determinations, both direct and calculated, is reasonably good. In the residue methods the FeO values for the chlorine method tend to be somewhat higher than those for the alcoholic iodine method, while the SiO_2 and MnO values are in good agreement.

There is a small variation in the Al_2O_3 values but this may be accounted for by segregation as a similar variation occurs in the chemical determinations already reported. The SiO_2 and FeO values for the fractional vacuum-fusion method are lower than those for the residue methods, and the MnO and Al_2O_3 values are higher.

X-RAY EXAMINATIONS

Acid-Extracted Inclusions (*Wm. Jessop and Sons, Ltd.*)—The weight of sample treated was 242 g. and the weight of residue obtained was 0·075 g. X-ray examination indicated the presence of a large amount of quartz and a medium amount of pyroxene of rhodonite type.

Photographs have been taken with both cobalt and manganese radiation, and only the latter gave low absorption, thus proving the presence of considerable amounts of a manganese-bearing compound.

Table IX

OXYGEN AND OXIDE DETERMINATIONS

Laboratory	Method	Bar No. and Size of Sample	Oxide and Oxygen as Percentage of Metal										Total Oxygen, %	
			SiO_2		FeO		MnO		Al_2O_3		Cr_2O_3	P_2O_5	NiO	Calculated	Direct
			Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen					
N.P.L.	Alcoholic Iodine	(1) 11 mm.	0·044 0·042	0·023 0·022	0·010 0·005	0·002 0·001	0·002 0·011	0·000$_4$ 0·002$_2$	0·001 0·001	0·000$_3$ 0·000$_3$	0·010$_3$ 0·013	0·004 0·003	Nil Nil	0·026 0·026	..
	Vacuum fusion	(1) 11 mm.	..	..	..	..	..	..	..	..	..	..	..	..	0·029
United Steel Cos., Ltd.	Fractional vacuum fusion	(3)	0·023$_3$	0·012$_3$	0·002	0·000$_3$	0·037	0·008$_3$	0·008	0·004	..	..	..	0·025$_3$	..
	Vacuum fusion		..	..	..	..	..	..	..	..	..	..	..	..	0·026
	Alcoholic Iodine		0·041	0·022	Present, but not determined		0·011	0·002$_3$	0·006$_3$	0·003	0·020	0·003	..	0·027$_4$	..
Brown-Firth	Vacuum fusion	(12) $\frac{3}{8}$ in.	..	..	..	..	..	..	..	..	..	..	..	..	0·025
J. Lysaght, Ltd.	Chlorine, 450° C.	(6) (i)* (ii)† (iii)‡	0·043 0·040 0·041	0·023 0·021 0·022	0·010 0·012 0·018	0·002 0·003 0·005	0·007 0·006 0·007	0·001$_3$ 0·001 0·001$_3$	0·002 0·001 0·002	0·001 0·000$_3$ 0·001	0·004 0·025 0·015	0·002 0·002 0·002	0·052 0·018 0·036	0·027$_3$ 0·025$_3$ 0·029$_3$	..
Stewarts and Lloyds, Ltd.	Chlorine, 500° C.	(8)	0·036 0·037	0·019 0·020	0·020$_3$ 0·017	0·005 0·004	0·004 0·004$_3$	0·001 0·001	0·003 0·005	0·001$_3$ 0·002	0·085 0·039	0·002 0·003	0·004 0·010	0·026$_3$ 0·027	..
Guest Keen Baldwins	Aluminium reduction	(4) 9 mm.	..	..	..	..	..	..	..	..	..	..	..	..	0·028$_3$ (end) 0·031 (middle) 0·028 (end)

* Extracted with cold water, washed with hot water, 3% Na_2CO_3, 5% HCl, 5% KCN, and finally with water.
† Extracted with alcohol, washed with alcohol, water, 3% Na_2CO_3, 5% HCl, 5% KCN, and finally with water.
‡ Extracted with hot water, washed with hot water, 5% KCN, 3% Na_2CO_3, 5% HCl, and finally with water.

Inclusions Extracted with Alcoholic Iodine Solution at 30° C. (National Physical Laboratory)—The weight of sample treated was 10 g., and 0·007 g. of residue was obtained. X-ray examination indicated the presence of a large amount of manganese sulphide and a small amount of silica (α-quartz). Rhodonite, if present, was in too small amount to be detected.

SUMMARY OF RESULTS

The results of the fractional vacuum-fusion analyses would appear to indicate that the oxygen-bearing inclusions are mainly of the manganese silicate type containing a proportion of tephroite. The presence of tephroite is not confirmed by the other methods. The results of the analyses by the residue methods indicate the presence of some manganese silicate, probably of the rhodonite type with excess of silica. The X-ray results indicate the presence of free silica with some silicate of rhodonite type as the oxygen-bearing inclusions and in addition manganese sulphide.

The microscopical examination also indicates the presence of manganese silicate, free silica, and manganese sulphide. The presence of alumina is also suggested in combination with the silicate and also as small stringers and particles. The amount of alumina determined by chemical methods is very small and it is possible that some chromium oxide (Cr_2O_3) may be associated with the aluminous inclusions observed under the microscope.

Further work is in hand on the identification of alumina and aluminous inclusions.

Part VI—A Co-operative Examination of the Distribution of Non-Metallic Inclusions in Billets from a Mild-Steel Ingot

By T. E. Rooney, A.M.C.T., F.R.I.C.

SYNOPSIS

Results are presented of micrographical examinations, X-ray examinations, and oxygen determinations by vacuum fusion and by the chlorine and alcoholic-iodine residue methods. In addition some determinations of nitrogen and hydrogen by the vacuum-fusion method are given. Sulphur has also beendetermined.

THIS paper represents the results of a co-operative investigation by members of the Gases and Non-Metallics Sub-Committee of samples taken from the top, middle, and bottom of a 45-cwt. ingot of mild steel in order to determine any differences in the amount and composition of the non-metallic inclusions in the three regions.

The co-operators taking part in the investigation were :

E. H. BOOTH	Wm. Jessop and Sons, Ltd.
G. F. CROSSLAND	Samuel Fox and Sons, Ltd.
A. J. K. HONEYMAN	Colvilles, Ltd.
R. E. LISMER	The United Steel Companies, Ltd.
I. M. MACKENZIE	Colvilles, Ltd.
G. MURFITT	Wm. Jessop and Sons, Ltd.
T. E. ROONEY	National Physical Laboratory
M. C. SANDERS	The Steel Company of Wales, Ltd., Port Talbot
J. SHAW	Wm. Jessop and Sons, Ltd.
C. W. SHORT	J. Lysaght, Ltd., Scunthorpe
H. A. SLOMAN	National Physical Laboratory
G. E. SPEIGHT	The United Steel Companies, Ltd.
J. E. WELLS	The Steel Company of Wales, Ltd. (formerly of Brown-Firth Research Laboratories)
T. H. WILLIAMS	Stewarts and Lloyds, Ltd., Corby

MANUFACTURE OF INGOT G9761

Details of the manufacture of the ingot (*G*9761) examined were as follows :

Composition of Charge

Pig iron	39 tons 10 cwt.
Scrap	36 tons 10 cwt.
Lime	3 tons 12 cwt.

Ladle Additions

Ferro-silicon	2½ cwt.
Ferro-manganese	9½ cwt.

Yield

Thirty-one narrow-end-up 45-cwt. ingots

Discard

Top 20%, bottom 3%, sufficient to remove fish-tail

Pit Sample Analysis

Carbon, %	0·215
Silicon, %	0·06
Sulphur, %	0·042
Phosphorus, %	0·029
Manganese, %	0·63

Samples—The samples were in the form of ½-in. bars, the prefix *G* representing those from the top, *H* those from the middle, and *J* those from the bottom of the ingot. The bars were forged from 2-in. square billets.

OXYGEN DETERMINATIONS

The results of the oxygen determinations are given in Table X.

The agreement between the values for total oxygen by the various methods is reasonably good, particularly as there is obvious segregation in the ingot. In all cases except one it is shown that the top section of the ingot contains less oxygen than the middle and bottom sections. Similarly the silica values by the residue methods with one exception indicate a lower proportion of silica in the top than in the middle and bottom sections. The ferrous oxide values, again with one exception, show very little variation in all three sections.

The manganous oxide values show a similar tendency to those for silica in that the top section values are lower than those in the middle and bottom sections.

MICROSCOPICAL EXAMINATION

Wm. Jessop and Sons, Ltd. Samples *G*5, *H*5, and *J*5

Longitudinal sections of the bars were prepared for micro-examination, and the sections were examined for cleanness and for type of inclusions present. Silicate stringers and sulphides were reported on each sample.

Brown-Firth Research Laboratories. Samples *G*12, *H*12, and *J*12

Sample *G*12 showed numerous sulphide inclusions, some silicates, particularly towards the outside of the bar, and a few duplex inclusions containing both sulphide and silicate. Samples *H*12 and *J*12 showed less sulphides and a more general distribution of silicates than did sample *G*12, the silicate reaching a maximum in *J*12, although the difference between *H*12 and *J*12 was slight.

United Steel Companies, Ltd. Samples *G*11, *H*11, and *J*11

Sample *G*11 was fairly dirty, the inclusions being unevenly distributed with segregation of the larger

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streaks towards the bar surface. The inclusion types were :

(1) Small elongated mono-phased sulphides tending to be streaky.
(2) Elongated duplex silicate sulphides (Fig. 37).
(3) Streaks of silicate of the aluminous type, occasionally large (Fig. 38).

In sample *H*11 the inclusions were more uniformly distributed than in *G*11, with large streaks randomly dispersed. The inclusion types were :

(1) Silicate of the aluminous type, much more numerous than in *G*11 (Fig. 39).
(2) Small elongated mono-phased sulphides.
(3) Elongated duplex silicate sulphides.
(4) Alumina particles and small stringers (Fig. 40).

The inclusions in sample *J*11 were similar in type and distribution to those in sample *H*11.

X-RAY EXAMINATION

Wm. Jessop and Sons, Ltd.

The non-metallic inclusions were extracted by a modified Dickenson method, and X-ray examination showed that in all three bars the inclusions were largely amorphous. The faint crystalline pattern could, however, be accounted for by the following phases :

(1) Manganese anorthite, $MnO.Al_2O_3.2SiO_2$
(2) Rhodonite, $MnO.SiO_2$
(3) Mullite, $3Al_2O_3.2SiO_2$.

This result was confirmed with both cobalt-radiation and manganese-radiation photographs. There are only insignificant differences in the relative quantities of these phases in the three samples.

It is quite possible that the amorphous phase could have been crystallized by heating and slow cooling, but unfortunately no more samples were available.

National Physical Laboratory

X-ray examination of inclusions extracted with alcoholic iodine solution at 30° C. indicated the presence of manganese sulphide (MnS) and constituents giving a more complicated pattern which could not be identified.

COMMENTS

In the extraction of the oxide inclusions by the modified Dickenson method, a sample of steel weighing 1500 to 2000 g. is preferred, but in this instance such a large amount of sample was not available and only 200 g. were used. This may account to some extent for the faintness of the X-ray pattern.

The method is designed mainly for the recovery of silica, silicates, and similar refractory inclusions. With this result in view the residue is treated with a strong solution of potassium permanganate, in order to oxidize carbonaceous material, and cleared with hydrogen peroxide. Further treatment involves boiling with dilute hydrochloric acid, washing with hot water and dilute sodium carbonate solution, followed

Table X

SUMMARY OF RESULTS OF OXIDE AND OXYGEN DETERMINATIONS ON STEEL CAST *G*9761

Laboratory	Method	Bar No.	Oxide and Oxygen as Percentage of Metal								Cr_2O_3	P_2O_5	Total Oxygen, %	
			SiO_2		FeO		MnO		Al_2O_3				Calculated	Direct
			Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen	Oxide	Oxygen				
N.P.L.	Alcoholic iodine	*G*7	0·015	0·008	0·007	0·002	0·019	0·004	0·001	0·000$_5$	0·007	0·004	0·014$_5$	
		*H*7	0·027	0·014	0·007	0·002	0·035	0·006	0·001	0·000$_5$	0·006	0·005	0·022$_5$	
		*J*7	0·027	0·014	0·006	0·001	0·033	0·007	0·001	0·000$_5$	0·008	0·005	0·022$_5$	
	Vacuum fusion	*G*7												0·011
		*H*7												0·020
		*J*7												0·022
United Steel Cos., Ltd.	Alcoholic iodine	*G*11	0·018	0·009$_5$	0·016	0·003$_5$	0·014	0·003	0·004$_5$	0·002	0·003$_5$	0·009	0·018	
		*H*11	0·026	0·014	0·011	0·002$_5$	0·028	0·006$_5$	0·005	0·002$_5$	0·004	0·004	0·025$_5$	
		*J*11	0·017	0·009	0·005$_5$	0·001	0·020	0·004$_5$	0·003	0·001$_5$	0·003	0·003	0·016	
	Vacuum fusion	*G*11												0·010$_5$
		*H*11												0·021
		*J*11												0·022
J. Lysaght, Ltd.	Chlorine, 350° C.	*G*10	0·015	0·008	0·008	0·002	0·009$_5$	0·002	0·002	0·001	0·013	0·002	0·013	
	450° C.	*G*10	0·013	0·007	0·006	0·001	0·009$_5$	0·002	0·002	0·001	Nil	0·002	0·011	
	350° C.	*H*10	0·022	0·012	0·008	0·002	0·022	0·005	0·003	0·001	0·015	0·002	0·020	..
	450° C.	*H*10	0·023	0·012	0·007	0·002	0·019	0·004	0·002	0·001	0·008	0·002	0·019	
	350° C.	*J*10	0·023	0·012	0·006	0·001	0·019	0·004	0·002	0·001	0·011	0·002	0·018	
	450° C.	*J*10	0·024	0·013	0·006	0·001	0·014	0·003	0·002	0·001	Nil	0·002	0·018	
Stewarts and Lloyds, Ltd.	Chlorine, 500° C.	*G*13	0·010	0·005	0·010	0·002	0·011	0·002	0·004	0·002	0·006	0·006$_5$	0·011	
	,,	*G*13	0·011	0·006	0·009	0·002	0·011	0·002	0·004	0·002	0·005	0·006	0·012	
	,,	*H*13	0·022	0·012	0·007	0·002	0·015	0·003	0·006	0·003	0·004	0·002	0·020	..
	,,	*H*13	0·019	0·010	0·007	0·002	0·014	0·003	0·006	0·003	0·004	0·002	0·018	
	,,	*J*13	0·019	0·010	0·005	0·001	0·015	0·003	0·007	0·003	0·003	0·001	0·017	
	,,	*J*13	0·021	0·011	0·005	0·001	0·015	0·003	0·007	0·003	0·003	0·002	0·018	
Brown-Firth Research Laboratories	Vacuum fusion	*G*12												0·012
		*H*12	..	..	..	..	..	..	..	..	..	..	..	0·018
		*J*12												0·019

by dilute hydrochloric acid and hot water. The final residue is ignited at a low temperature. This treatment serves to concentrate the more refractory portion of the non-metallic inclusions.

In contrast to this procedure, for the extraction of the non-metallic inclusions by the alcoholic iodine method, only 10 g. of sample are used. The temperature is controlled at about 30° C. in order to retain sulphides. The relatively strong lines of manganese sulphide tend to mask the faint lines of the silicate constituents. Also rhodonite tends to occur mainly in an amorphous or glassy condition. It is probable that a microscopic examination of the residue after removal of carbon by a low-temperature ignition may yield further information on the nature of the inclusions.

SULPHUR DETERMINATIONS

Sulphur determinations were made by two laboratories in order to determine whether there was any difference in the percentage of sulphur in the samples prepared from the three sections of the ingot. The results represent the average sulphur contents in each section and are as follows:

Laboratory	Sample	Sulphur Contents, % Top (*G*)	Middle (*H*)	Bottom (*J*)
United Steels	11	0·042	0·041	0·040
Colvilles	3	0·042	0·041	0·041

SUMMARY OF RESULTS

(1) The results of the oxygen determinations by the vacuum-fusion method and by the residue methods indicate that there is a larger proportion of oxide inclusions in the middle and bottom sections of the ingot and that the principal inclusions are silicates of manganese.

(2) The sulphur determinations, in contrast, indicate that all three sections contain a similar amount of sulphide. It was not possible to investigate local segregation in the ½-in. bars examined, and the results represent average values on the ingot sections.

(3) Microscopic examination confirms that the principal inclusions are silicates with some manganese sulphide.

(4) X-ray examination of residues extracted by the Dickenson method indicates the presence of two manganese silicates, *viz.*, manganese anorthite and rhodonite and some mullite and silicate of aluminium.

(5) Inclusions extracted by the alcoholic iodine method confirm the presence of manganese sulphide and other constituents with a more complicated pattern.

Acknowledgments

Some of the work described in Parts IV, V, and VI was carried out in the Metallurgy Division of the National Physical Laboratory, on behalf of the British Iron and Steel Research Association. Parts IV, V, and VI are published by permission of the Director of the National Physical Laboratory and with the approval of the British Iron and Steel Research Association.

A Vacuum Furnace For High-Temperature Microscopy

By D. G. Nickols, B.Sc.

SYNOPSIS

A vacuum furnace has been constructed to enable metal specimens to be kept under microscopic examination while at temperatures up to 950° C. It incorporates a mica observation window and gaskets of heat-resistant silicone rubber. Constructional details are given and future developments indicated.

THE apparatus described was constructed for preliminary investigations on high-temperature microscopy. It has now been operating for some time, and since it incorporates features which, as far as is known, have not appeared in previous furnaces,* a short description may be of interest.

The furnace is shown assembled for operation in Fig. 1. It is waxed directly on to the steel flange of an oil-diffusion pump which, backed by a rotary pump, evacuates it when running. The vacuum produced is sufficient to prevent any oxidation of the steel specimens, or of the molybdenum heater, during operation.

Details of the furnace body are given in Figs. 2*a* and 2*b*. The lower part of the body is double-walled, and cooling water passes through the space between the walls. The upper part consists of a solid brass ring to which the cover is attached. A gasket of silicone rubber, which fits into a recess in this ring, gives a vacuum-tight seal between body and cover. Three hooks are screwed into the inner face of this ring, and a refractory triangle is suspended from them. The heater, which consists of twelve turns of 0·016-in. molybdenum wire wound on an alumina plate ¾ in.

* H. Esser and H. Cornelius: *Stahl und Eisen*, 1933, vol. 53, p. 532.

Manuscript received 1st October, 1948.

Mr. Nickols is a member of the staff of the Physics Laboratories, British Iron and Steel Research Association, Battersea.

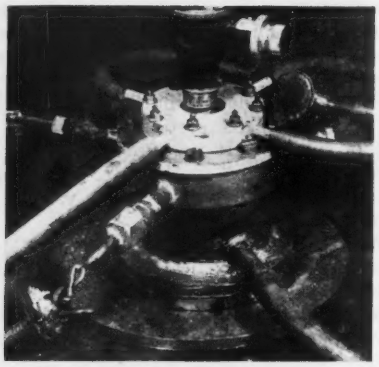


Fig. 1—Furnace assembled for use

square by $\frac{1}{8}$ in. thick, rests on this triangle. A similar alumina plate rests on the heater, and the specimen, S, rests on this plate. The specimen is approximately $\frac{1}{2}$ in. dia. and $\frac{1}{8}$ in. thick, and has a radial hole drilled in it. Its temperature is measured by a chromel–alumel thermocouple, T, inserted into this hole. Both heater and thermocouple connections are

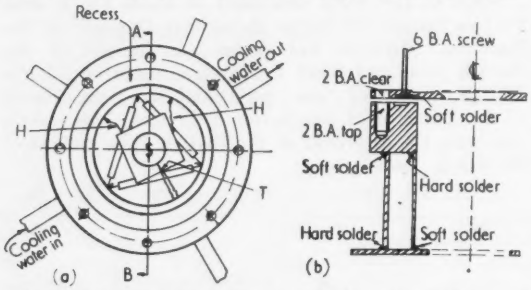


Fig. 2—(*a*) Plan of upper part of furnace body, and (*b*) half-section at AB of furnace, and part of cover

taken out through glass-to-metal terminal seals. The thermocouple wires are connected directly to the leads of a twin seal, but the heater connections, H, are made *via* heavy copper leads.

The furnace cover is in two parts (*see* Fig. 3). The first has a recess for a gasket on which rests the observation window. Both gasket and window may be seen in place in Fig. 3. The window is of mica, 0·002 in. thick, and cut roughly to a circular shape. The other part of the cover rests on the window and is fixed as shown in Fig. 1. This part is water cooled and has ports through which air is blown to cool the objective.

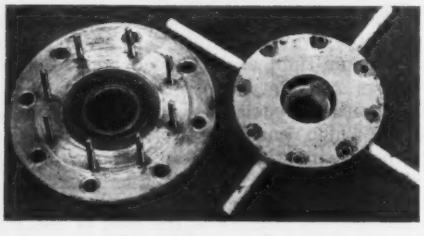
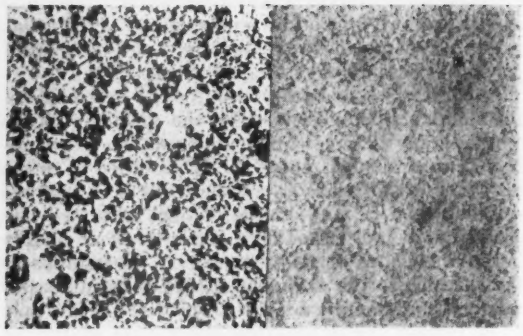


Fig. 3—Furnace cover unassembled



a *b*

Fig. 4—Specimen of hypo-eutectoid steel, (*a*) at 20° C., and (*b*) at 780° C. Both × 80

Fig. 4*a* shows the surface of a carbon steel, originally mechanically polished, but unetched, after heating for one hour at 800° C., and slowly cooling to room temperature. Fig. 4*b* shows the same area of the same specimen when reheated to 780° C. and photographed at that temperature. Other photographs have been taken at temperatures up to 950° C.

The apparatus is now being modified for use with 35 mm. film in order to obtain continuous records of transformations in steels. The use of a reflecting microscope will also enable much greater magnification to be obtained without reducing the distance between the specimen and the objective.

Acknowledgments

The author wishes to thank the Metallurgy Department, Royal Aeronautical Establishment, Farnborough, for a most helpful discussion on this work.

FORTHCOMING B.I.S.R.A. PAPERS

The following papers, received from the British Iron and Steel Research Association, have been accepted for publication, and will appear in forthcoming issues of the *Journal*:

"*The Interpretation of Fouling Samples from Ships*," by K. A. Pyefinch, M. W. H. Bishop, and M. F. Spooner.

The paper describes the kind of results that can be obtained, and deductions that can be drawn, from a set of samples of the fouling from a ship.

"*The Calculation of Stresses in the Ironing of Metal Cups*," by R. Hill.

Describes a theory of the stresses required to iron a cup by forcing it through a die with a close-fitting internal punch.

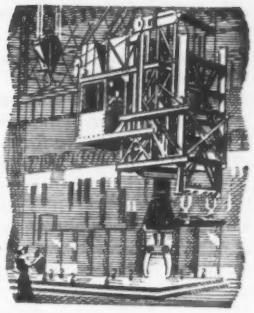
"*The Application of Dry-Coke Cooling Plants to Integrated Iron and Steel Works*," by L. H. W. Savage and A. V. Brancker.

Comparison is made of three types of cooling plant and their influence on coke-oven operation. Costs, and fuel and power balances are discussed.

"*The Layout of Integrated Steelworks*," by H. H. Mardon and J. S. Terrington.

A comprehensive review of selected steelworks in Great Britain. The report considers the development of a theoretical analysis of basic layouts and gives recommendations for further projects.

IRON AND STEELWORKS ENGINEERING



THE IRON AND STEEL ENGINEERS GROUP

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REPORT OF THE SEVENTH MEETING

THE SEVENTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4, Grosvenor Gardens, London, S.W.1, on Tuesday, 22nd June, 1948. Mr. W. F. CARTWRIGHT (Steel Company of Wales, Ltd.), Chairman of the Group, presided.

AT THE MORNING SESSION a paper on "Electric Control Gear for Steel-Mill Auxiliaries," was presented by Mr. R. A. WEST. The discussion was published in the November issue of the *Journal*.

AT THE AFTERNOON SESSION Dr. J. C. READ introduced the discussion on a paper on "Electronic and Servo Electronic Controls and their application to the Iron and Steel Industry," which had been presented at the Morning Session by Dr. W. G. THOMPSON. The Session continued with a discussion, introduced by Mr. R. DINGWALL, on the paper, "The Maintenance of Electrical Machinery in Iron and Steel Works," presented by Mr. G. S. MARTIN. The discussions on both papers are given below.

PROCEEDINGS OF THE AFTERNOON SESSION: 2.0 P.M. to 4.30 P.M.

Discussion on ELECTRONIC AND SERVO ELECTRONIC CONTROLS AND THEIR APPLICATION TO THE IRON AND STEEL INDUSTRY*

Dr. **J. C. Read** (British Thomson-Houston Co., Ltd.): I should like to add a little to what Dr. Thompson has said on rectifiers for the larger rolling-mill drives, and particularly for hot-strip mills.

In two or three years' time an interesting comparison will be available between different rectifier arrangements for this purpose, as it is likely that four different hot-strip mills will be operating, fed by rectifiers with contrasting schemes. These mills are: (1) the Dinslaken hot-strip mill, installed by Siemens Schuckert Werke in Germany just before the war, using pumped water-cooled rectifiers totalling 12,000 kW., operating 6-phase, and having a separate rectifier for each mill motor; (2) an installation for Italy, nearly completed by Allgemeine Elektricitats Gesellschaft at the end of the war and, I believe, to be finished partly by Compagnia Generale di Elettricita, using pumped water-cooled rectifiers totalling 14,000 kW., 12-phase, and again having a separate rectifier for each mill motor; (3) a hot-strip mill recently ordered for Denain-Anzin in France, which will have Westinghouse pumped ignitrons totalling 15,000 kW.; and (4) the hot-strip mill now under construction for the Steel Company of Wales, Ltd., with B.T.H. pumpless air-cooled rectifiers totalling 21,000 kW., 60-phase, with all rectifiers and all mill motors operating on a common D.C. busbar.

Of these, the British equipment will be not only the largest but also the only one that takes advantage of what we hold to be the latest improvements in simplification and economy in rectifier equipments.

Although it is true, as Dr. Thompson has mentioned, that the common busbar system results in a slight saving in total rating of plant, I think its more important advantage is that it gives a very good prospect of being able to run through backfires without their affecting the rolling process. When each motor has its own rectifier, as in the Dinslaken and Italian equipments, any backfire inevitably results in the strip cobbling and breaking, the mill stops, and a fresh start has to be made. The maintenance of correct relative speeds of the successive stands is also a little easier with the common busbar scheme. The common busbar can result in somewhat larger possible fault currents, but methods of dealing with that problem have been evolved and I am confident that it is not going to give us any difficulty in the Steel Company of Wales installation. The shock on the A.C. system in the event of backfire will only be of the same order as it would have been if each motor had had its own separate rectifier equipment.

As regards the number of phases, I think one of the lessons of recent years has been that the practice, particularly on the Continent, of putting these very large loads on A.C. systems with only 12- or even 6-phase was

* *Journal of The Iron and Steel Institute*, 1948, vol. 158, Apr., pp. 497–509.

wrong ; such large loads should work with a considerably larger number of phases. The choice of 60-phases was partly a matter of convenience, and the main thing is that the number of phases is being made large enough for the rectifier wave form to be practically a sine wave.

The advantages of rectifiers for hot-strip mills, as compared with motor generators, are : (*a*) The cost is usually lower ; (*b*) the size, weight, and cost of the building can be substantially less ; (*c*) the light-running loss is only a small fraction of that of the motor generator (and the full-load efficiency also is higher), and the resulting saving in total energy consumption is quite large ; and (*d*) the maintenance cost is reduced by the elimination of brushgear.

With such a strong case for rectifiers, it appears to me that their use for purposes of this kind has been remarkably slow in developing, both in this country and in America. It does not seem that there has been any sufficient reason for this slowness. Rectifiers have been used, of course, for many years for other loads where the need for reliability is quite as great as in this type of duty.

The advantages of the rectifier drive, while particularly noteworthy for hot-strip mills, are by no means negligible for several other types of rolling mill. On the Continent quite a large number of mills of various kinds have been equipped with rectifiers in the last few years, and I think we may expect wider use of them in this country. Wherever specially complicated controls are necessary, the rectifier has two additional advantages, namely, firstly, the response to the controlling device is immediate, and secondly, there are no troublesome effects due to residual fields.

Mr. C. E. Dew (Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd.) : A practical difficulty to be overcome is the training of electricians on the maintenance of electronic control systems. All control systems have been the result of a gradual evolution from earlier types, and the maintenance electrician has been able to familiarize himself step by step with changing circuit design, but electronic control represents a fundamental departure from present practice, and he therefore commences his maintenance task at a disadvantage in having no fund of accumulated experience on which he can draw.

Mr. **J. P. Parker** (Messrs. McLellan and Partners) : Dr. Read omitted one important advantage of rectifiers over motor-generator sets for hot-mill drives, and that is the size and cost of high-voltage switchgear. Three motor-generator sets would probably be required for the installation to which he refers, each set having a driving motor of approximately 10,000 h.p. The switchgear for such machines would probably be of the order of 1000 mVA. With rectifiers, the switchgear would probably be rated at only 500 mVA.

One reason why rectifiers have not been generally applied to the main drives of hot mills in the United States, may be that there is there an instinctive dislike of gadgets. However, now that this country has gone ahead with the first comprehensive installation, it is interesting to note that two similar installations for France and Australia, the plant for which is being made in America, will have rectifiers.

If separate groups of rectifiers had been used for each motor in the installation to which Dr. Read referred, the installed rectifier capacity would have been 25,200 kW. instead of the 21,000 kW. installed for the common busbar system.

Mr. **J. Higson** (Messrs. Dorman, Long and Co., Ltd.) : I inspected recently a complete electronic equipment used in conjunction with a plastics mill. It was installed in a new building in which everything was clean, and there was none of the dust and dirt associated with steelworks, but I was informed that trouble had been experienced because of dust. It is my opinion that for successful operation of electronic equipment in steelworks very serious consideration must be given by the manufacturers to making the equipment dust-tight, and very considerable thought and care must be taken to develop really robust apparatus.

Some of the valves and valve holders used for the electronics have very small clearances and I am perturbed at the possibility of these small clearances being present on equipments supplied to steelworks.

I have had considerable experience of servicing and trouble-finding in amplifiers operated in much better conditions than are present in steelworks, and from this experience I would make the following comments :

(1) Equipment should be supplied as dust-tight as possible and installed in a dust-free atmosphere

(2) The equipment should, where possible, be supplied as " plug-in " units to allow for quick replacement in case of trouble, the plugging contacts being made of a suitable non-corrosive metal

(3) Clearances in the equipment must be carefully examined to ensure that they are suitable for steelworks use

(4) The servicing of electronic equipment is greatly facilitated by the use of an oscilloscope, and special facilities will have to be provided for servicing defective apparatus. This work is in my view a specialist job and is beyond the scope of the average electrical maintenance man in a steelworks, although a few men could be selected and specially trained.

Mr. **L. Rothera** (Messrs. Colvilles, Ltd.) : Previous speakers have stressed the question of maintenance of rectifier units. We have had a considerable number of such equipments working for many years under steelworks' conditions, the first group being installed in 1930, and have had no trouble worth mentioning on any of the equipments, nor have we found the dust problem at all serious. I agree with Mr. Higson that each unit of a bank should be easily disconnected without interfering with the remainder of the bank, and multiple units give greater security against total shut-down.

The steep rising voltage on very light load may cause trouble with lamps, but I understand that this point is likely to be overcome.

We have found this class of machinery to be extremely reliable and easily maintained.

Mr. **F. L. Parkin** (Messrs. Steel, Peech and Tozer, Ltd.) : Manufacturers are very electronic-minded at the moment and they tend to put forward electronic control as the answer to all our problems. In complicated applications electronics are justified, but many simple problems can be dealt with by other means.

Turning to maintenance, it appears that a specialist is required to look after the apparatus. I should like to suggest that manufacturers should consider a training scheme by which works could send a senior electrician for a course in studying electronic control from the point of view of maintenance. We are bound to have at least minor troubles and points requiring attention, and they may be somewhat complicated for the electrician who has not had any experience in electronics.

Mr. **K. F. Shrubb** (British Iron and Steel Research Association) : We are coming against the problem of maintenance over and over again as engineers explain that they cannot instal electronic-control gear until men are available who understand it. I cannot help thinking that the solution will be found in some form of training scheme. The effort will be a big one, but I do not see how it can be avoided.

The sort of work being done at the moment is the Diploma Scheme of the Association of Supervising

Electrical Engineers, and control-gear training schemes offered by some manufacturers.

The United Steel Companies, Ltd., have prepared a code of instrumentation within their own group, and out of that suggestion there may come the idea of forming a national code of instrumentation. Dr. Chesters, in a recent statement, pointed out that one really wanted to go further than that. A national code could be issued something like a British Standard, but there would also be a need for an explanatory book for the staff who use the equipment. Such a book would be much in the form of a textbook, but Dr. Chesters pointed out that it should be similar to the best form of instruction manual that we came to know during the war.

Electronic equipment is forming a much larger part of instruments nowadays, and if such a manual takes the title " The Efficient Use of Instruments " we might go further and have a book on " The Efficient Use of Control Gear " to help to overcome the present lagging behind of technical colleges in training in electronic equipment.

Mr. Dew pointed out that there are at present very few training facilities for existing maintenance staff. Fortunately, to understand much of this new control gear needs no more than an appreciation of the new exposition of very old principles. Dr. Thompson, for instance, used the term " closed-cycle control system " in his paper. The term may sound new, but the idea is not. We must appreciate that the word " control," from its definition, must inherently imply a closed-cycle system. " To control " means " to move in a restrained fashion " and the idea of restraint implies judgment. Judgment implies that one must know where the machine ought to be and where it is now, and unless there is that appreciation of the difference between those two quantities, which is of course the error, there would be no such thing as control. The definition of control as merely appreciating the error that exists in any form of control system makes us realize that any control system must have a human being at the beginning of it, though his job may merely have been to set a predetermined programme in an otherwise automatic system.

This directs our attention to the use of the techniques of operator response which were developed during the war. It is probable that steelworks' equipment can be analysed from an operator-response point of view. Some of the most obvious places are where the man's instantaneous response is an inherent part of the equipment, such as on cranes, roughing stands, and forging hammers and presses. The application of combined speed and position control may substantially improve the overall performance. A crane control system has already been proposed which embodies both speed and position control of the hook at will. A ready application for that seems to be in the forge, where the crane, acting as manipulator, would be set to do what the smith has been doing for many years with his hands.

Mr. **N. R. D. Gurney** (Metropolitan-Vickers Electric Co., Ltd.) : One speaker has suggested that electrical manufacturers are endeavouring to persuade steel manufacturers to purchase more electronic equipment, but I think that the opposite is nearer the truth.

The problems which the users of electrical equipment are putting to the electrical manufacturers are daily becoming more complex and more difficult to solve by the familiar methods of control. The electrical manufacturer is therefore turning more frequently to this newer technique to solve the problems put to him, and is finding that electronic equipment, especially with servo systems, is of very great value.

In a special rolling mill now being built, continuous screwing down of the top roll in proportion to the growth of the product is desired. This is obviously an application for a servo electronic control, such as was used and largely developed in the war for gun control. We are therefore trying to make use of the knowledge and experience gained during the war to solve some of the problems with which the steel industry now confronts us. So far electrical manufacturers have not had a lot of experience in this country of electronic-control equipment in steelworks, and some practical problems may have to be solved to make electronic equipment as reliable as other electrical equipment.

Mr. Higson has already mentioned a possible source of trouble in contamination of valve pins and holders owing to the sulphurous nature of the air in steelworks, and it has yet to be found out what effects these conditions will have on the reliability of electronic equipment. To obtain more information we are arranging some tests on an electronic amplifier to discover what degree of corrosion may be expected on such equipment when unprotected in a steelworks, and where corrosion is likely to occur.

I think the author will agree that the correct solution of any control problem lies in the utilization of the simplest and most reliable means to attain a given end, and only where electronic control meets these conditions is it the correct tool for the job.

Mr. **B. Randell** (Messrs. Head, Wrightson and Co., Ltd.) : During a recent visit to a factory in which electronic equipment is made, I was rather appalled to find that there was a remarkable lack of standardization in the components used. For example, in this particular equipment I saw a mixture of British, American, and International valve types. I do feel that it is worth while making a plea to manufacturers of electronic apparatus to try to establish some degree of standardization in the equipment they use. This is particularly important where valve bases are concerned, since standard bases allow of easy interchange in an emergency.

With regard to unit construction of the items, and plug-in connections, the communications industry in this country has for many years been using these principles in many of their types of apparatus, thus greatly facilitating replacement and maintenance work. It is highly desirable that we should follow the lead of the communications engineer as we come to use more and more electronic equipment in the industry.

Mr. **J. E. Boul** (English Electric Co., Ltd.) : The paper calls attention to the wide scope of application open to the mercury-arc rectifier. I am very pleased to see this because I feel that the adoption of the grid-controlled rectifier as a source of variable-voltage supply for variable-speed drives has, until recently, been rather neglected by British engineers in the heavy-plant field,

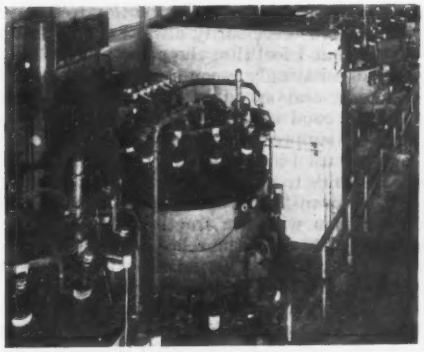


Fig. A—8000-amp. 420-V. grid-controlled rectifier

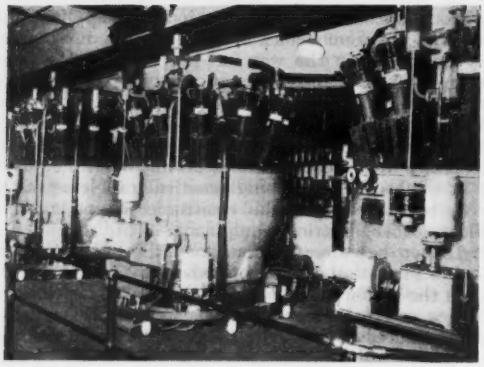


Fig. B—41,000-amp. 675-V. grid-controlled rectifier

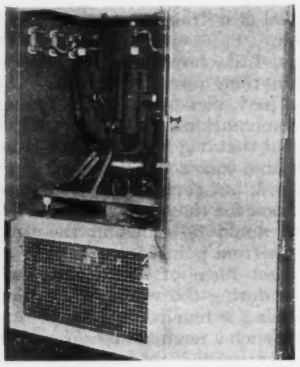


Fig. C—Grid-controlled rectifier

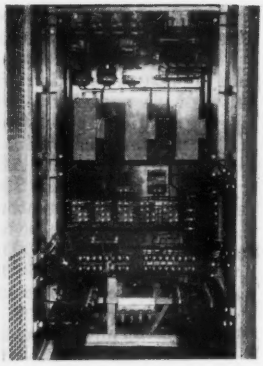


Fig. D—Static grid-control apparatus

despite the experience gained by their colleagues in the electro-chemical industry. Some very large installations of grid-controlled rectifiers for this purpose have been successfully employed, and I should like to reinforce, if I may, the author's references on p. 508 to large variable-voltage grid-controlled rectifier schemes which have been carried out in this country.

Dealing first with electro-chemical applications, Fig. A shows an 8000-amp. 420-V. equipment, and Fig. B shows a 41,000-amp. 675-V. equipment. Both of these are for aluminium production, and both employ grid-controlled rectifiers for D.C. voltage variation over a wide range. The first-mentioned equipment has now been converted from its wartime use of aluminium production to a peacetime use of providing a variable-voltage D.C. supply to a 12,000-h.p. compressor-motor drive in which extremely close limits of automatic constant-speed control are required over a range of 0 to 100%.

Another example of variable-speed drives by grid-controlled rectifiers, which is now under construction, is that for a 1200-h.p. wind-tunnel motor requiring constant-voltage control at any speed from 0 to 100%. Figure C shows another type of grid-controlled rectifier, and Fig. D the static grid-control apparatus for it.

A point to be borne in mind is the essential simplicity of the basic elements of the rectifier. Smooth voltage control from 0 to 100% can be obtained simply by operating on a potentiometer to give a change of current in one of the grid circuits from $-0{\cdot}3$ to $+0{\cdot}3$ amp. at a low voltage. When such an operation can be satisfactorily performed by the use of a normal electromagnetic relay, then I suggest the simple relay should be employed in preference to the more complex electronic control which is shown in all of the author's diagrams. It was probably not the author's intention to imply that electronic control is necessarily always the best form of control to use, but I feel that the point needs clarifying.

I would unhesitatingly recommend electronic control where accuracy and speed of response are of prime importance. A good example is an electronic relay for high-speed arc suppression of grid-controlled rectifiers which has been used in this country on many occasions. The relay responds to overcurrent in the primary-supply to the rectifier transformer and applies negative bias to the rectifier grids within a fraction of a second. The standard arrangement of the relay incorporates a 5-way test switch which permits periodic routine testing of the circuit components and their settings without the need for external test apparatus. In order to guard against valve failure in the period between routine inspections, two thyratron valves are connected in parallel in such a way that the relay is operative even though one valve may fail. Simultaneous failure of both valves is highly improbable.

In connection with the use of grid-controlled rectifiers for variable-voltage supplies, the proportionate reduction of power factor with voltage is sometimes held up as a drawback to their use. The disadvantage is more apparent than real because the voltage and power are usually reduced together, and in what is probably the worst case, *i.e.*, a constant-torque drive, there is no increase in total kilovolt-ampères drawn from the line.

Referring to Fig. 13*a* of the paper, I should be interested to know what is, in the author's view, the maximum frequency for which the mercury-arc rectifier is suitable.

Mr. P. F. Grove (Messrs. John Miles and Partners (London), Ltd.) : When I was engaged on the construction of the Grid system, some time ago, I remember that the heavy electrical manufacturers of the 132,000-V. sub-station equipment were somewhat lacking in the technique of making small, reliable, tripping relays which were necessary for the multi-circuit protective interlocking. We went to the makers of automatic telephones, and, although this was a novel step at the time, these people had a new mentality. This proved a success in producing smaller and cheaper relays capable of working many thousands of times longer than those associated with the heavy manufacturers.

Electronics is just another step in developing the thinking side of automatic control which is now entering every industry. In iron and steel works, for instance, the simple A.C. or D.C. partly automatic rheostatic control for blast-furnace hoists is replaced by an automatic system, whereby a scale-car operator can turn one miniature control handle and cause the whole cycle of operation for charging a furnace to take place automatically, with further facilities for varying the cycle and adjusting it at will. Steelworks' engineers have observed the possibilities of electronic control for some time, but would perhaps like to hear from Dr. Thompson some reports of electronic applications in practice and what are some of their troubles. For instance, the strip-mill installation in Germany is now comparatively old, but any accurate knowledge of its operation would be welcome.

At the other end of the range of electronics are the extremely sensitive controls to be seen on small motors, and although Dr. Thompson states that response is very quick, it would be interesting to know the effect of time lag between the many components of a complicated control system such as he has indicated.

In steelworks at present there are signs of transition from contactor-type control, as described by Mr. West, to the Post Office type of relay equipment, but electronic

devices should be better from the point of view of dust. I am a little wary of Post Office relays because of the amount of maintenance continuously necessary in an automatic exchange. Furthermore, the effect of introducing this machinery into steelworks' atmospheres is an unknown factor at present. To offset this, much is being done nowadays to improve the accommodation for electrical equipment in clean and air-conditioned rooms.

I cannot see any mention in the paper of the life of electronic tubes, which is an important factor in relation to operating cost. This is demonstrated by the more costly application of high-frequency induction flow-melting of electrolytically tinned steel strip, compared with simple conduction heating which is cheaper to maintain.

Mr. **A. L. M. Douglas** (British Iron and Steel Research Association) : There are some weaknesses on the lighter side of this technique. All forms of electronic control, as now understood, rely on valves of one kind or another. A certain amount of this mechanism has given trouble because it is not easy in this country to buy a valve which is really suitable for industrial use. The major production of valves is governed by the requirements of the radio industry, and valve manufacturers seem unwilling to design special valves which will stand up to severe industrial use for really long periods of time.

The Post Office and some of the services require valves which must be very reliable, but often these valves are not available or are not suitable for the kind of circuits that are wanted by the steel industry. A glass valve is rather frail, and it seems a pity that it has not been found possible to persuade the manufacturers to produce valves of the consistency or the interchangeability of many of the American types, especially the all-metal ones.

There has been reference to the diversity of valve types and bases. That is a thing we should not have to put up with now ; it ought not to be necessary to have half-a-dozen different base fittings in the one amplifier. Manufacturers in general have standardized types, but they are very frequently improving these types, and in doing so they alter the characteristics, so that a valve bought from *A* is probably different from that bought from *B*. That does not happen in the United States ; any valve of a specific type bought from any manufacturer will be the same as the equivalent one bought from another manufacturer. If the lighter form of control gear is to be successful, some pressure should be brought to bear on the valve manufacturers to make them realize that these things are required, and that they will be used if they are made.

A minor point to which I would refer is the question of contacts. It is very difficult indeed to find any material which will stand up to sulphurous atmospheres. I have used valve apparatus in steelworks for a great many years experimentally, and have not been able to find any combination of materials which is really proof against the attack of gases. No doubt that problem will be solved, but I think that as far as the early valves in the control system go—and they are the most important ones—something must be done to provide a satisfactory contact if it is not possible to remove the primary measuring or controlling elements from hot gaseous zones.

Mr. **W. H. Sykes** (English Electric Co., Ltd.) : There is one side of electronics which has hardly been mentioned in the paper, and that is its application to instrumentation. Most of the paper deals with servo mechanisms and the application of electronic control to servo mechanisms, but the whole list of conversions mentioned in Table II is applicable to instrumentation, such as measuring temperatures, light intensity, torque, etc. In addition, there is another form of instrumentation that will probably be of interest, and that is vibration measurements, which I feel can be carried out satisfactorily only by electronic means.

To deal now with the question of maintenance, which has been mentioned by several speakers, the manufacturers are endeavouring to make this problem as easy as possible from the user's point of view. Owing to the comparative cheapness of electronic gear, compared with the equipment it is controlling, it requires only a small extra outlay to provide spare units of electronic gear. Means of changing over from the operational chassis to the spare unit can be accomplished either with change-over switches or with the plug-in type of chassis, so that if a fault occurs on the one it can be replaced by the spare unit with a minimum of time lost. The control gear then becomes 100% reliable, and the fault in the unit can be found at the convenience of the maintenance staff without any interference with the full operation of the equipment.

There are no moving parts in electronic gear, and so maintenance is merely a case of checking valve currents and voltages, or of collecting a few readings on a meter. Jack plugs can be, and should be, provided on the chassis for this purpose, with either external or internal metering facilities. By this means a continuous check on valve conditions can be kept, and it soon becomes evident when one begins to lose its emission. A change at this stage will thus avoid a total shut-down.

Although we have heard numerous advantages of electronics there is one drawback relating to the hot-cathode type of thyratron valve, and I think it should not be overlooked. The disadvantage is due to the fact that the mercury has to be vaporized before it becomes safe to use. An appreciable heating time of approximately 5 min. is required for most of these valves, but some of them need as much as 15 min. This matter can be overcome on spare units by arranging to have the valves continuously preheated, but for initial starts this point should not be overlooked.

The **Chairman** (Mr. W. F. Cartwright) : I would like to put one question to Dr. Thompson—the sort of question that is in the mind of the ordinary steelworks' operator. Does Dr. Thompson foresee the time when, instead of a mass of resistances and contactor panels, we may have a few little boxes and some wireless knobs to control the whole thing from a very neat little cabin ?

AUTHOR'S REPLIES

Dr. **W. G. Thompson** (General Electric Co., Ltd.) replied : Dr. Read has given a most interesting summary of the developments which have taken place in the application of mercury-arc rectifiers to steel-mill drives, and the result of the comparison he mentioned will be awaited with interest.

The modern rectifier, in particular the steel-tank pumpless type, is sufficiently free from backfires to enable a choice of independent drives, as against grouping the rolling-mill motors on a common busbar, to be made on the widest possible technical and mechanical basis. The total kilowatts of the machines to be installed and the size and speed of operation of the D.C. switchgear are important factors. With high-speed control switching by electronic means, it should be possible to suppress, isolate, and reclose the rectifier in $\frac{1}{10}$ sec. so as to make the individual drive as safe as the group drive, if necessary, and thereby to maintain the freedom of choice for the mill designer.

In the case of very large equipment, as mentioned by Dr. Read, I agree that the equivalent of a large number of phases should be used, but with smaller units the inherently simple 12- and 6-phase circuits have much to

commend themselves. This is particularly so because its phase multiplication can be effected only through complication of the rectifier transformers, or alternatively by the introduction of phase-shifting auto-transformers with low reactance.

An important point in the development of these multi-phase arrangements is that electrical designers have realized the measures which have to be taken in dealing with phase-displacement transformers so as to bring their reliability into line with that of the ordinary power transformer. In building up these multi-phase units there is always the question of whether to make the basic unit 12-phase or 6-phase. The 12-phase transformer has the advantage that twice the amount of reactance can be built into the transformer for a given voltage regulation. On the other hand, some designers prefer the more simple robust construction of the 6-phase transformer, which can also be used in groups to give multi-phase operation ; but I think the steel industry can rest assured that, as far as phase multiplication is concerned, the electrical industry is fully aware of the issues involved and of the requirements best suited for any given job.

A number of rectifier applications to rolling-mill and drawbench work will be going into service during the next few years ; some of these will have full electronic control and will add further to the comprehensive list of advantages enumerated by Dr. Read.

Mr. Dew's anxiety about the training of electricians will, I am certain, prove only temporary. Not only have many of these workers proved adept at the construction of radio receivers of all kinds, but their numbers have been reinforced by people returning from the Services with a good experience of electronic gear. Our experience so far has been that properly designed and installed electronic equipment has proved remarkably free from trouble of the abstruse kind, and simple adjustments only have been required.

Mr. Parker has mentioned the important advantage in the cost of switchgear being in favour of rectifier equipment. Not only is this a question of economics, but also if the rectifier can do the job better than the motor-generator set—as rectifier engineers believe it can—I think there is no doubt that it will finally come to be the standard and accepted way of deriving large D.C. powers from the A.C. network. I think also that there is no doubt that the static method of conversion will eventually take the whole field.

Mr. Parker mentioned the delay in the use of rectifiers in American steel mills, and from figures quoted it would appear that there is a tendency in America to work with lower voltages where the efficiency of the rectifier is not so marked.

Mr. Higson emphasizes the important point in the dust-proof enclosure of electronic equipment for installation in steelworks. In my opinion either of two main courses should be adopted : either vital parts should be totally enclosed with adequate surfaces for heat distribution, or they should be forcibly ventilated with suitable air filters provided at the inlet.

Chassis-mounted amplifiers of the plug-in type are the standard practice of at least one leading manufacturer in this country and are much to be commended. As we are not, in general, involved in short-wave technique in industrial electronics, there is no reason why clearance and layouts should not be to engineering standards rather than to standards used in radio practice.

Portable oscilloscopes are now plentiful and relatively cheap, and, with suitable instruction manuals, servicing should not be difficult.

Mr. Rothera confirms the reliability of rectifier equipments in steelworks ; the rise of voltage on light load, due to the interphase transformer, can be overcome by automatically switching-in a loading resistance below about 1% load. This is a standard feature on many rectifier installations.

Mr. Parkin pointed out the necessity of selecting the right kind of application of electronic control, and this can best be ensured by providing complete information for the manufacturer at the enquiry stage. The coiler is recognized by electronic engineers as an application calling for considerable judgment in design, particularly as it demands increasing torque with decreasing speed. Several excellent means are available for reducing speed with increasing diameter of the coil, without involving tension control.

In view of the interest taken by the universities and technical colleges in industrial electronics, I am sure that adequate training facilities in the elementary principles of the subject will become increasingly valuable.

Mr. Shrubb also has raised the question of training. There are quite a number of electronic handbooks on the market which give good general instruction and, in addition, manufacturers usually supply suitable instruction booklets with their equipments. Mr. Shrubb made some interesting comments on some suitable applications for the technique of operator response which were developed during the war. It has now been generally recognized that these methods are suitable for dealing with all types of control problems, particularly as not only has the behaviour of electrical and mechanical systems working in combination been studied, but so also has the typical response of the human operator. Although it is customary to regard certain manually operated systems as being of the open-loop type, they are, strictly speaking, no longer open-loop when it is realized that the human operator is really a closing link in the system. By this I mean that he receives an optical signal from the work through the human eye, which is processed through the brain and muscles of the arm to give a control at the handwheel or lever. Where the nature of the operation reaches the limits of human response, we get exactly the same problems of 'overshoot' and 'hunting' as are manifest in automatic controls when they are applied to jobs beyond their capabilities. The remedy in the latter case is to improve the design !

Mr. Gurney's comments provide an interesting practical example of previous speakers' remarks, and I have no doubt that properly designed screwdown controls of the types he mentioned would be very effective.

With regard to the question of contamination of valve pins and holders, owing to the sulphurous nature of the air in the steelworks, I think the experiment which Mr. Gurney is carrying out will give very valuable results, but in any case there is still the remedy of totally enclosing the amplifier equipment so as to prevent sulphurous fumes from reaching the parts in question.

Mr. Randell rightly draws attention to the standardization of components, particularly valve types, but fortunately the range of valves used in electronic control is likely to be small compared with that required in communications. There is no need to go outside this country for valves suitable for control purposes. The ideal is to use valves which are replaceable locally. The Octal-base types have frequently been used in this country, but the design of a complete new series of valves for industry is unlikely to meet with much response from valve manufacturers unless the quantities are sufficient to warrant special types. The plug-in type of connection is, of course, appreciated in the design of electronic-control equipment, but in my opinion it should be limited to light-current circuits.

Mr. Boul emphasizes the scope of the grid-controlled rectifier and, in the conversion of plant from aluminium production to compressor drives, brings out the ubiquitous nature of this type of plant. The ease with which large powers can be controlled with absolute precision by currents of $\pm$ 0·3 amp. is indicative of the resources now available to the control engineer. I am inclining more and more to the use of electronic control in preference to the normal electro-magnetic relays, even for simple applications, because of the absence of moving parts and contacts. If static conversion is right in principle for large power units, then it should be even more so for control units ; so far as electro-mechanical relays are concerned, I would accept the Post Office type as being equivalent to electronic control, and preferable to some of the heavier types developed by power engineers.

The question of using two valves in parallel as a safe precaution is one which is frequently raised. My own views are that the gain is more apparent than real, that it is only effective against surprise failure when accompanied by routine inspection, as described by Mr. Boul. In general, I have assumed about 3000 cycles to be the practical limit for a mercury-arc rectifier. From the point of view of the manufacturer who makes rotating machines, there seems little point in interpolating mercury-arc rectifier oscillators in, say, the 1000- or 2000-cycle range, whether both above or below this range, *i.e.*, up to the 10,000-cycle range the inductor alternator is a well-established piece of equipment.

Mr. Grove makes very valuable comments on the contribution of the communications industry to the control problems of the Grid system, and his remarks confirm our experience with industrial electronic controls. We are finding that it is rarely the electronic equipment which fails, or even gives trouble ; grid-controlled switching permits the sparkless operation of contactors, and this has eliminated contact burning, but the usual mechanical troubles associated with the maintenance of contactor gear are still to be found to some extent. These mechanical troubles will appear because of the reduced amount of attention given to contactors in the absence of burning on the contacts, but, on the other hand, once a mechanical fault is found in these circumstances, the immediate steps which are taken lead to the elimination of the trouble in future. Hence, with mechanical parts operating in conjunction with electronic gear, not only a better electrical performance but also a better mechanical performance is obtained.

I agree with Mr. Grove that electronics is just another stage in developing the thinking side of automatic control, and in fact we are already beginning to regard electrical control systems without electronic features as being of a lower order of response.

I have already referred to the absence of troubles encountered with electronic control. The strip-mill installation in Germany is not a particularly appropriate example because it was installed without a proper appreciation of modern servo theory, and considerable modification was required before it was finally satisfactory ; various items, including the electro-mechanical tension control, gave trouble from causes which were not understood at that time, but which today would be obvious. I have no doubt that the system, if started afresh, could now be redesigned to operate perfectly satisfactorily. The effect of time lag between many components is to cause a tendency towards oscillation, but here again it is the aim of the electronics engineer to counter this tendency in the design stage by including phase-advancing means and suitable stabilizing feed-back networks, and to ensure the necessary difference between the time constants of the appropriate parts of the circuit. The new technique enables these steps to be taken without recourse to laborious trial-and-error methods.

Automatic telephone exchanges with many thousands of components are not comparable with industrial gear, except inasmuch as the maintenance per component is extremely low. The amount of maintenance of Post Office relays in individual electronic equipments has so far been nil, and the introduction of these into a steelworks' atmosphere should present no difficulty, provided that proper precautions are taken. The life of electron tubes has often been raised ; the valve manufacturers are invariably conservative in any figures they quote, being unwilling, for obvious reasons, to state any specific life. Although practical experience has shown that in isolated instances a valve can fail immediately it is switched on, usually it will carry on for several thousand hours. This means that failures are eliminated in trying out the equipment at the works, and such failures have so far been very few indeed. Valves are easy to replace, and with circuits properly designed to " fail to safety," the equipment should not give cause for a moment's anxiety. The high-frequency flow method of treating electrically tinned strip is now not regarded as an entirely ideal application for high-frequency electronics, as less costly methods are available.

I cannot accept Mr. Douglas' view on the frailty of valves. They were subjected to much rough treatment during the war ; they were shot out of guns as part of proximity fuses, and dropped by parachute, and were usually the one component in good condition if the parachute failed to open. Mechanically, a valve consists of a low-inertia structure of great stiffness in a vacuum container. I can conceive of no better engineering construction than the valves of the radio receiving type ; the larger transmitting-type valves are of course more delicate, but if suitably housed are capable of excellent mechanical performance. I hold no brief for the American valve industry against the British. I have discussed some of their so-called special industrial lines with our valve designers and I am convinced that a standard valve, suitably rated, could give a performance equally as good as the type from across the Atlantic.

Mr. Sykes brings out some very good points in connection with instrumentation. In view of his remarks, and those of previous speakers, I welcome endorsement of the policy of jacking components or sections of the equipment for checking or overhauling. The emergence of new gas-filled types of valves will, I am sure, overcome the time delay disadvantage which he mentioned in regard to the hot-cathode type.

In reply to the Chairman, I feel that the experience in the driving of high-speed devices such as automobiles, trains, aircraft, or ships at sea cannot be ignored, for, despite tradition, the tendency is to rely more and more on instruments, and to provide the controller with greater comfort as an aid to better concentration and response. In due course, many more industrial operations, including those in steelworks, will be controlled with gear of the electronic type with the operator working free from disturbance in a control cabin and assisted by a complete range of instruments.

CORRESPONDENCE

Mr. **A. A. L. Bentall** (Metropolitan-Vickers Electrical Co., Ltd.) wrote : The author states in his paper that the term " electronic control " should be restricted to systems incorporating high-vacuum valves in the early stages of the control cycle. It will help, therefore, to form a more complete record of electronic-control applications if some mention is made of systems in which alternative power-amplifying devices are used. The more important of these are transductors, metadynes, and normal D.C.

generators, but there is also the hydraulic system in which the control valve can be actuated by the output of an electronic amplifier.

Some examples of different combinations which may be used in electrical systems may now be quoted :

(1) For drives which require two or more D.C. motors to be accurately synchronized, the error signal, obtained as the difference of two tachometer-generator voltages, may be applied, after electronic amplification, to the motor fields by means of a transductor (*i.e.*, a special type of saturable-core reactor).

(2) For position controls, hard valves may be used to excite metadynes (or other similar machines), which are special D.C. generators having a very high power amplification and also a high rate of response. In drives requiring up to 15 or 20 h.p., the metadyne will supply the full power to the armature of the controlled motor and inherent current limitation can be incorporated, so avoiding the need for a slipping clutch ; for higher power applications the metadyne can excite a standard generator, which gives the main power output.

(3) Some cases may arise in which it is practical to use hard valves for controlling vapour devices, which in turn excite the fields of normal D.C. generators, on motor-generator sets provided with flywheels. This arrangement, as well as relieving the mains of very severe peaks where reversing duty is concerned, also avoids duplication of the large main-power rectifiers required for the ' figure-of-eight ' connection.

Overriding or limit controls often play an important part in closed-cycle systems, and their introduction may be facilitated by the use of transductors or metadynes in conjunction with electronics, as electrical continuity is then avoidable between different parts of the circuit.

Mr. **S. A. Ghalib** (Metropolitan-Vickers Electrical Co., Ltd.) wrote : One of the main obstacles to the more extensive application of electronics to industrial processes is the lack of maintenance staff with experience in electronics.

Although electronic equipment as a whole, and electronic components in particular, have proved their reliability both in industry and in war service, this type of equipment is often regarded as a potential source of trouble, and the possibility of failures and their effects are very much exaggerated.

Experienced maintenance staff would give the necessary confidence to the user, but the present position has to be faced and, therefore, I endorse the author's remark and entirely agree with him that the aim of the electronics engineer is to obtain optimum fidelity with the minimum of components. Unfortunately this point is not brought out forcibly in the examples of typical applications given in his paper. On p. 508, for instance, in connection with the regulated D.C. voltage provided by grid-controlled mercury-arc rectifiers, it should be pointed out that an accuracy of 1% from " no load " to " full load " and a recovery time of 0·04 sec. can be achieved, not with the use of an electronic amplifier, but with simple saturable reactors. Such an accuracy is adequate for this particular application. Electronic control of the grids of the mercury-arc rectifier should only be used when even greater accuracy, of the order of 0·1%, combined with rapid response, is essential.

Again, the author refers to the use of electronic amplifiers in connection with speed control (pp. 506 and 507), and Fig. 20*a* shows a chassis-mounted electronic amplifier for such a control. For the majority of applications covered by the paper the accuracy required can be obtained by the use of a magnetic amplifier in the servo system. Such systems can maintain the speed constant to within a few revolutions per minute from " no load " to " full load," over a speed range of 100 : 1. The use of electronic amplifiers should be limited to cases where the speed has to be maintained constant to within a fraction of 1 r.p.m.

Figure 17, on p. 506, utilizes four, or possibly more, valves, as the high-tension supply is not shown. The same result, *i.e.*, a control current proportional to the acceleration of the mill motor, has been obtained very satisfactorily by the use of a magnetic amplifier. I am not suggesting that valves are not reliable, but at present the valveless scheme appears to give more confidence to the maintenance staff, and consequently to the user.

In general, the use of electronic control, as distinct from electronic power units such as mercury-arc rectifiers and thyratrons, should be limited to : (*a*) positional controls, which are inherently more difficult to stabilize than speed controls, (*b*) speed, voltage, current, horsepower controls, when extreme accuracy is essential, and (*c*) photo-electric controls.

Finally, I should like to sound a warning, lest the author has unintentionally given, on p. 503, the false impression that it is possible to predict with accuracy the response and performance of a large servo. The response to unit function, and particularly the harmonic response, are very useful as far as they go, but servo designers know only too well that the most difficult part of the problem is to obtain accurate data on the various elements of the system and to assess the effect of the non-linear quantities. The higher the performance required, the more serious this effect becomes. At best the mathematical analysis gives a first approximation. Perhaps the greatest advantage of electronic-control equipment is the ease of adjustment it provides, so that the stabilizing components can be modified to give the optimum performance when the equipment is installed.

Mr. **T. W. Barton** (Whitehead Iron and Steel Co., Ltd.) : A number of speakers stressed the importance of trained personnel and Dr. Thompson stated that the universities were now giving lectures on this equipment, but these will not be of much service to the man in the shop. In common with other potential users we are of the opinion that a form of textbook, commencing with the basis of electronic engineering, is now urgently required by the industry, and until this is made available the science may possibly be frowned upon by many people.

As Dr. Thompson will be aware, we have tension-controlling equipments employing vibrating contacts, carbon piles and rotating regulators, and in one case vibrating regulators, together with electronic equipment. Although we consider that the rotating regulator is at the present time the most efficient, partly due to the fact that it requires considerably less maintenance than the vibrating contact regulator, we do feel that electronic equipment properly combined with rotating regulators will ultimately supplant the other forms of equipment.

He will also be aware that we are experimenting, on a small scale, with a pure electronic tension scheme, but before considering larger units we have to consider the possibility of hunting due to deformation in the coiled strip. One typical example may be quoted. A wide cold-reduction reversing mill, rolling strip at 1000 ft./min., will have an empty reel-drum speed of nearly 200 r.p.m. and a full reel speed of some 60 r.p.m. During build-up, any variation in the strip tension due to the shape of the coil on the leading reel will have a decreasing frequency, and in the reverse manner an increasing frequency for the trailing reel. As we understand that the feed-back loop is tuned to approximately one frequency, how will hunting be prevented during this period ? When using other forms of regulator it is easy to dampen them sufficiently to prevent this having any undue effect on the strip, but it is not apparent that this

can be achieved in an electronic system. Perhaps Dr. Thompson would explain this point further.

AUTHOR'S WRITTEN REPLIES

Dr. **W. G. Thompson** wrote : Mr. Bentall gives some interesting alternative methods of amplifying the control signal from the electronic equipment by means of electromagnetic, electrodynamic and electro-hydraulic systems. There is no doubt that each of the systems has applications for which it is superior to others and, therefore, without prejudice to special cases, I will confine myself to the following general comments. The systems mentioned will, in general, have greater time lags than the purely static types of control ; both the saturable reactor and, even more so, the metadyne where the characteristics have to be built into the machine, may require further adjustment and partial re-design after installation. An electro-hydraulic system is frequently sensitive to temperature due to viscosity changes. The electronic-controlled motor-generator set can offer advantages on the score of cheapness where reversing duty is required, provided the response is satisfactory from the technical standpoint. Although the isolation between different sections of the loop is, as pointed out in the paper, more easily attainable where machines are used in cascade, I would not accept this as a decisive reason for the adoption of a machine amplifier.

Mr. Ghalib puts the case for saturable-reactor control. I am aware that they can be used for the more simple forms of control, but I do not consider them suitable for a more comprehensive control, even where extreme accuracy may not be required. In some instances they may be unsuitable because of changes in supply frequency. I would not be dogmatic on the ranges of application of the electronic and reactor controls because so many other factors usually enter into the problem. So far I have not come across any instance where electronic control has been turned down on the grounds of having no maintenance staff available. With regard to the prediction of the response of servos, I think the position is now a little better than Mr. Ghalib suggests. In the first place it was not my intention to convey the idea that the response to unit function was the sole criterion, but the theory of the subject is still undergoing development, and the success of various methods of attack are constantly being brought to my notice.

In reply to Mr. Barton, there are now a number of textbooks dealing with the subject of electronic engineering, but I feel that experience with even a fairly simple piece of industrial electronic-control equipment will teach much more than it is possible to convey to the user by means of a textbook. I am pleased to have Mr. Barton's opinion that the electronic-control equipment will ultimately be preferred to other types for tension-controlling apparatus. I should say that the critical frequency of any part of an electronic-control circuit would be much higher than those produced by deformations in a coiled strip when running through the range of 60–200 r.p.m., and that hunting is therefore not likely to arise. There is in any case the electrical equivalent of mechanical damping which is usually much more easy to apply than in the mechanical regulator.

Discussion on THE MAINTENANCE OF ELECTRICAL MACHINERY IN IRON AND STEEL WORKS*

Mr. **G. S. Martin** (Lanarkshire Steel Co., Ltd.) introduced the paper, and gave a summary of its contents.

Mr. **R. Dingwall** (Dorman, Long and Co., Ltd.) : Maintenance men frequently feel that they do not always have the final say in regard to initial expenditure. I suggest that the remedy is in our hands. Those responsible make their decision on the basis of what they are persuaded is the most economic job, all things considered, and if the engineer considers that higher initial expenditure is justified, it is surely up to him to substantiate his claim and put his case more forcefully.

The authors favour having a special squad for the major plant renewals to relieve the maintenance men. I agree, but in the larger works I would go a step further and relieve the maintenance engineers themselves of detailed responsibility for plant renewal and extension work by handing it over to an installations department, wherever the main organization permitted this. The maintenance engineers should be free to concentrate on maintenance, avoidance of stoppages, and investigation of stoppages. But I would also call them in frequently and regularly for consultation on design and development work in connection with all new plant development. In this way the ideas of the maintenance men, born of experience over many years, might be incorporated in new plant and more consideration given to the suitability of plant and plant lay-out from the maintenance point of view.

The authors refer to the desirability of recording systematically the nature and causes of breakdowns. I consider this particularly important on motors and machines generally ; in our own organization we have a very complete system of motor record cards and, further, of drive record cards. As a result, we can build up over a period a valuable history of plant performance, switchgear, and control-gear performance. The main point I want to make is that the maintenance engineer's job does not stop there. He must get this information back to the manufacturers ; and where we have put this into practice we have found the manufacturers very willing to co-operate.

Maintenance engineers seem to realize the advantage of a period of training with manufacturers, but the manufacturers do not appear to realize the advantage of their designers having a period of training on iron and steel works' maintenance. I would therefore suggest interchange schemes for young engineers in training.

Mention is made of main-drive equipment where, after 25 years, the insulation appeared to be almost as good as new. I should like to have further opinions about the life that may be expected from insulation on main-drive equipments, and when, if ever, one should go in for a policy of complete rewinding.

There are two aspects of standardization. The manufacturers regard it from the point of view of reducing manufacturing costs. Maintenance engineers, on the other hand, regard it as a means of achieving interchangeability of equipment made by different manufacturers, and the urge towards this objective must come from the users. In the steel industry we have standard D.C. mill-type motors, for which I believe we have to thank the iron and steel engineers in America. There is a real need for standardization of industrial-type A.C. motors for application both in the iron and steel and in general industry, and I mention this because I hope that some

* *Journal of The Iron and Steel Institute*, 1948, vol. 158, April, pp. 510–520.

time the Iron and Steel Engineers Group may do something about it. Standardization of couplings also, is most desirable. In our organization, for some years we have adhered to a range of standard couplings for all new drives, and we have no doubts about its value.

Mr. R. A. Lake (Lancashire Steel Corporation, Ltd.) : Regarding our skid problems, we have found it a great advantage to include a step of permanent resistance in the skid drive to limit the maximum torque to about 200%, and I wonder whether the authors have tried that.

We have never found scoring and grooving of commutators to occur when the air is really clean, although I agree with the authors that once it has started it is very difficult to stop, because the action seems to be progressive.

With regard to control, we have found on many cranes that delays are reduced by fitting panels, etc., which they did not originally have. An embarrassing trouble to deal with is when a crane is stuck in a furnace, which sometimes occurs due to an arc-over inside a controller. On the more important cranes we have put either one or two contactors outside the controller just to break the current. The controller does the reversing and the resistance stepping, but the contactor, operated by one of the fingers of the controller, breaks the current finally, so that when the driver pulls off hurriedly, the main arc is on the contactor. We have also found that the drum controller is remarkably good for the light horse-powers, and is less trouble than the cam type, owing to its rugged simplicity.

Mr. **M. Y. Harvey** (Colvilles, Ltd.) : I think it is generally understood that a dirty atmosphere is only one of many factors which can lead to commutator grooving and scoring. The two machines referred to in the paper are not running in a particularly clean station and we were at first inclined to think that grit was the cause of the trouble. However, the fact that one of these machines ran with an almost perfect commutator surface for 6000 hr. before grooving began does not support that theory. On the machine indicated in Fig. 6, an effort was made to arrest the grooving on the two tracks shown by removing the oxide film from the rest of the commutator. This was not successful, probably because the grooving was rather deep, so we now intend to turn or grind the commutator and experiment with a different grade of brush. The other machine commutator was turned and a new set of brushes was fitted, and it is interesting to note that a brush seating stone was used for bedding them in, with the result that the commutator never looked like developing a proper skin. We believe that this was due to particles of the seating stone being embedded in the brush contact surfaces, and the machine was therefore taken out of service as soon as possible. The commutator was stoned and the brush contact surfaces cleaned with glass paper. As an experiment on this machine, when brushes require renewal and if only new brushes are available, we renew all the brushes on one arm. Those which have been removed are stored for future use, except of course the ones which are worn to the limit, and since these used brushes are properly bedded and have an oxide film on their contact surfaces, they can be used to replace odd brushes on any arm. The purpose of this procedure is, of course, to reduce the possibility of selective action caused by mixing new brushes, which have no oxide film, with existing brushes which have.

Mr. **G. H. Davidson** (Dorman, Long and Co., Ltd.) : The authors point out that too much stress should not be laid on initial expenditure and, like Mr. Dingwall, I agree wholeheartedly. What really matters is the cost per ton of finished steel for each plant item, and after all, interest and depreciation charges are usually only a small percentage of total costs taken over the lifetime of the equipment.

I would like further details of the system for planned maintenance. How much clerical work is involved, and has it been found possible to inspect the plant at pre-arranged intervals, particularly items which are in almost continuous operation ? Has a comprehensive maintenance system been considered such as that described by Nicol ?*

The authors state that breakdowns are kept to a reasonable level, but no figures are quoted. Actual figures would have been useful. I find that on a group of three mills in which I am interested, the time lost due to electrical breakdowns (expressed as a percentage of total operating time) varies from 0·3% in a steam-driven billet and sheet-bar mill, to 0·47% in a 20-in. section mill equipped with electrical main drive.

During the past few years I have subdivided mill electrical breakdowns into the following headings :

(*a*) Wiring and cabling faults
(*b*) Switch and control-gear faults
(*c*) Motor faults
(*d*) Failure of supply
(*e*) Main-drive faults

Generally speaking, switch and control-gear faults account for over 50% of total breakdowns, motors account for about 25%, and the other headings share the remaining 25% in varying proportions. The switch and control-gear faults are usually of very short duration, but they are the most frequent, and it is surprising how they mount up in the course of a year.

Having found the weak links, the engineer must consider what can be done to strengthen them, either by altering his maintenance system, provision of improved material, or design alterations ; the last step is usually carried out in conjunction with the manufacturers.

Some performance figures for motors would have been interesting. For instance, what is the average length of run between breakdowns on mill auxiliary drives ? With a group of A.C. mill motors manufactured in 1937, I find that the average run per drive between breakdowns is about six years. These figures are based on records extending over a ten-year period and include various makes and sizes of motors, from 25 to 75 h.p. Some of these motors have given considerable trouble, but others have run literally trouble free. For example, out of one batch of 25 motors, 23 have run for ten years without breakdown. I do not wish to revive the A.C./D.C. controversy at this stage, but I must say that on the score of reliability, we obtain fair results from our A.C. auxiliaries. We were somewhat reassured to note that the authors apparently require three winders to service approximately 650 motors. Against this, on one group of works, we employ nine winders to service 2900 motors, 80% of which are A.C.

Do the authors use tapered-shaft extensions on auxiliary drives, and if so, are any special precautions taken in machining and fitting the half couplings or pinions ?

I am rather surprised to note that switches are examined after tripping six times. Surely they should always be inspected at the first available opportunity if they have cleared a severe fault, whereas they could be allowed to open on normal overloads a considerable number of times without inspection.

Further information on lay-out and equipment of the repair shop would be of interest. My personal opinion is that an electrical repair shop should be as self-contained as possible, complete with its own lathes and

* J. C. B. Nicol, *Journal of the Institute of Electrical Engineers*, 1945, vol. 92, Part 2, No. 27, June, pp. 166–176.

other machine tools. A sheet metal worker is a useful man to be attached to a large repair shop, in addition to the tradesmen listed in the paper. I cannot quite follow the remark at the top of p. 516, where it states that it is easier to plan rewinding work through the repair shop. Does this mean that armatures are rewound after a certain life when motors come in for overhaul ? It would appear that it might pay to do this on motors which have been in service for a considerable number of years on heavy-duty drives, rather than wait for them to fail in service. I agree that vital auxiliaries should be changed at intervals of two to three years.

The authors recommend small step-down transformers for portable tools and hand-lamps. What voltage do they suggest, and have they experienced difficulty in obtaining equipment ? Cross-traverse control wires in the body of the crane are very inaccessible for maintenance electricians, and do not necessarily lead to increased safety. We recently had a distressing fatality when a man slipped while working at the straining points of wires installed in this manner. I prefer traverse conductors on the top of the crane, well fenced with expanded metal guards. The gate giving access to the traverse conductors should be mechanically interlocked with the main isolating switch. A Castell type of interlock is suitable for this purpose.

Mr. **M. Y. Harvey** : Mr. Davidson's figures of electrical plant performance are interesting and I shall give some approximate figures for three mills in which I am interested, although I do feel that comparisons of this nature can be misleading unless the plants are reasonably comparable and similar factors have been taken into consideration in each case.

On a steam-driven 42-in. cogging mill, equipped with modern mill-type motors and control gear, the time lost due to breakdown of the mill auxiliaries is only 0·04%, but including time lost on soaking-pit and stripper cranes, this figure is increased to 0·5%. The time lost on the 34-in. billet mill and the 32-in. section mill is 0·1% and 0·2% respectively.

According to the figures given by Mr. Davidson for motors per armature winder, it would appear as though we were overstaffed. Here again, however, comparisons are difficult unless cognizance is taken of the degree of motor standardization, age of the plant and condition of machinery which the motors have to drive, and any other duties the winders may have to carry out. For example, our backlog of motor repair work is not particularly heavy, but because we have many different types of old motors and few spares for these, we must endeavour to tackle repairs to these quickly. Also, I presume that of the total of 2900 motors, a fair proportion will be of the squirrel-cage type which as a rule do not require much servicing and are much simpler to repair than D.C. machines. The 650 motors referred to are all D.C.

On the subject of repair-shop practice, I agree that an electrical repair shop should be as self-contained as possible, and at the works with which I am connected we have most of the machine tools we require.

The point raised about a suitable voltage for portable tools and hand-lamps is one about which I would not like to offer advice, since much depends upon the circumstances under which these have to be used. I do feel however, that the factory department's recommendation to use 110-V. portable tools, fed from the secondary winding of a 1-phase transformer with an earthed centre tap, should help to ensure reasonable safety in most cases. For portable hand-lamps 24 V. should be quite safe in most cases, although for work inside metal enclosures, it may be more desirable to use 12-V. equipment.

Mr. **T. A. Hogarth** (Llanelly Steel Co., Ltd.) : I think that closer collaboration between the mechanical and the electrical maintenance men is very desirable. Statistics of electrical breakdowns show that quite a fair proportion are due to mechanical faults. An armature shaft breaks and on investigation it is discovered that the motor seat has loose rivets, the motor-feet bolts may have worked slack, or the brake wheel or coupling may be slightly eccentric on the armature shaft. This is classified as an electrical breakdown and so it is, but it is due to mechanical defects. I have seen a report come in stating that the mill output was down due to the slow running of the live roller gear feeding the mill. This was entered as an electrical delay and blamed on the speed of the motor. After some investigation and a good deal of trouble the electrical side was found to be in good condition, but a length of line shaft had been renewed the previous day and the brasses fitted too tightly. The result was excessive friction and hence the reduction in speed. These are only two examples of what can happen in steelworks, but I think you will agree that they emphasize my point.

Mr. **G. H. Tomlinson** (Walter Somers, Ltd.) : We have a number of cranes, the heaviest being of 80-tons' capacity, and with three exceptions all are of the usual cage-controlled type. The 60-ton and two 30-ton cranes are floor-controlled and serve steam hydraulic-driven forging presses. They are subjected to most severe duties and require a great deal of supervision and running repairs. We get trouble with the downshop leads or trolley wires which are fixed overhead from the roof trusses. As many as 15 to 18 trolley wires are required for a four-motor crane and these accumulate deposits from the high concentration of fumes arising from the furnaces.

We get arcing from the spring-loaded trolley-wheel collectors, which have to be changed frequently. Carbon collectors have been tried in place of trolley wheels, but due to the fixing ears and splicing sleeves which are placed at intervals, we found that the carbons splintered and broke, and we had to go back to trolley wheels.

Carbon collectors are good on plain trolley wires which are suspended from each end, such as the cross trolley wires along the crane girders. We find they have a long life and, due to their wiping action, make very good contact.

I would like to stress the necessity for an understanding between electricians and millwrights, because both come into the picture on nearly all repairs. To save time on major repairs I have found it profitable to take the men into one's confidence and plan out the respective jobs with them beforehand.

Regarding crane driving, I think that only in recent years has it been recognized as more than a semi-skilled job. Crane drivers have costly and important machines to operate, and by careful driving they may do much to eliminate stoppages and serious breakdowns, and also, by anticipating requirements below, may speed production tremendously.

Mr. **R. P. Middleton** (F. H. Wheeler (Sheffield), Ltd.) : Financial control sometimes insists upon a contract being put out on price only, but the maintenance engineer can often argue the case and, if successful, ensure a well-designed plant with a lower maintenance cost. The maintenance engineer should insist on a first-class installation with a strict adherence to current I.E.E. regulations, standardization of equipment as far as possible, and adequate space for installation of equipment with necessary access. Then, and then only, will maintenance mean " maintenance," not " running repairs ! "

I believe a scheme, sponsored by a responsible body, could be evolved to enable an interchange of younger men between various plants and contractors of repute,

to provide them with more varied experience. This would supplement the present educational system which is based largely on book knowledge.

Mr. **R. A. West** (Igranic Electric Co., Ltd.) : I have seen the results of good, bad, and indifferent electrical maintenance and I would like to suggest that money spent in the employment of highly trained conscientious personnel will be rewarded by freedom from breakdown and costly delays and repairs. I have visited steelworks for so many years that I cannot escape the conclusion that many managements do not agree ; apart from the question of rates of pay, maintenance work should not be withdrawn at idle periods when overworked machinery ought to receive every attention possible. During the war the R.A.F. created a large pool of technicians for this type of work. A very high grade was necessary for the electrical equipment on aircraft, especially radar, and the quality was obtained by training men who had a good educational standard. This is the grade required in steelworks today ; I have seen the need with contactor gear, and with electronic gear it will be even more necessary. As industry progresses so less crude labour and more skill is required to operate the plant, and I would like to join hands with the authors of these two papers in asking managements to get schemes into operation which will ensure a steady supply of the right grade for electrical maintenance.

Mr. **G. S. Martin** : With regard to Mr. Dingwall's remarks about the insulation of main-drive motors, the comments in the paper referred to a 25,000 peak horsepower drive consisting of four motors, mechanically coupled in line, driving a cogging mill. Two of the motors were 25 years old and, although there was no particular reason to suspect the insulation, it was felt that after such a long period of service it was desirable to rewind the armatures. Somewhat to our surprise, the insulation was in remarkably good condition. Mica is practically indestructible, and if the insulation is largely composed of this material it will probably last indefinitely. If, however, there is a good deal of cotton in the insulation and the motor operates at a high temperature, the insulation will deteriorate and possibly shrink. If the windings remain tight in the slots there is little cause for worry, but if shrinkage has taken place, usually indicated by slack wedges, mechanical failure of the insulation is possible and it is time to anticipate breakdown. The cost of a rewind is comparatively small compared with the cost of a serious breakdown, and, since expenditure is fully justified after a long perid of working, it is suggested that when a motor has been in commission for 25–30 years it is time to consider a complete rewind.

We considered fully planned maintenance but decided to start with a simple system, find out how it worked, and extend and improve it as time went on. We have endeavoured to cut down clerical work to a minimum, and a fully comprehensive system does involve a fair amount of clerical work.

At the works with which I am associated there is a 40-in. blooming mill, a 36-in. three-stand section mill, a 27-in. two-stand section mill, a small 18-in. mill, and a melting shop, turning out about 6000 ingot tons per week. One man does all the inspection, and he has one clerk to assist him. He works to a definite rota, and, based on experience, may inspect certain sections of the plant at intervals of, say, 3 or even 6 months, whereas other sections may be examined every fortnight. The inspector also instructs section electricians to provide inspection reports, and these have given good results, as the men are naturally averse to any reflection on their ability by an adverse report, and consequently keep their plant in good condition.

Reports, together with action taken, are noted on a card index ; anything which may cause early breakdown is dealt with immediately, and some of the work is necessarily detailed to be carried out at the week-end. Inspection report cards are placed in a rack conveniently situated for scrutiny by the electrical engineer and foreman. When a particular job is completed the foreman indicates what has been done on the card, posts this in an adjacent rack, and the details are finally recorded in the permanent card index. This enables anyone to see from day to day the progress of necessary work brought to light by the inspection system. It has been found possible to inspect much of the plant at pre-arranged intervals, but on continuous working units inspection can only be arranged in conjunction with any stoppages.

In a large steam-driven blooming mill, about 75% of which is modern, the time lost due to electrical breakdown (expressed as a percentage of total operating time) is 0·52%. The auxiliaries on these mills are driven by D.C. motors, and we find the average life is about five years.

All our auxiliary-drive motors have tapered-shaft extensions. Where couplings are required they are machined in a lathe, the taper is checked by gauge, and the holes drilled to jig.

If I may amplify the remarks on p. 516, we happen to be unfortunate enough to have few spares for a large number of old open-type motors, most of which are situated in places difficult of access. If two of these motors break down within a short time of each other we have to work right round the clock to have them repaired. We now take them out at specified intervals and rewind armatures or field coils, and carry out repairs at our leisure.

It is difficult to obtain low-voltage equipment, but where we can purchase, we prefer to step down to 24 V.

I agree entirely with Mr. Hogarth and Mr. Tomlinson regarding co-operation between electrical and mechanical departments. Where there are two engineers, one electrcal and one mechanical, I think it is desirable to have a chief engineer, part of whose duty it is to make the two departments appreciate that they must work as a team.

The remarks by Mr. Middleton and Mr. West are very much to the point. I do not think the works engineer is consulted often enough before the installation of new plant, and although the modern plants which I have seen bear tribute to the skill of our designers, it is not very difficult to point out small things which make maintenance difficult, but which could have been overcome easily by consultation between designer and maintenance engineer.

The modern trend of education is rather disturbing, the emphasis being on higher education followed by technical education. Good education does lead to a fuller life, but it must be remembered that the large majority of people in heavy industry are labourers or craftsmen, and require very little, if any, higher technical knowledge. It would appear that much time will be wasted unless the number of persons to whom such training is given is related to the requirements of industry.

Another disturbing factor is that the " sergeant major " or foreman type of job is becoming increasingly difficult to fill. The standard of boys applying for work in steelworks seems to be lower than before. The majority of those who do come appear to be quite content to do just sufficient to enable them to be classified as a craftsman, while a small percentage wish to drive ahead and become the manager. That most vital job of foreman does not appear to have any attraction.

N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Forthcoming Meetings

Annual General Meeting, 1949

The Annual General Meeting of The Iron and Steel Institute will be held in London on Wednesday and Thursday, 27th and 28th April, 1949. A Luncheon for Members is to be arranged for Thursday, 28th April, 1949.

A proposal to amend certain Bye-Laws will be submitted at this meeting. Formal notice of this proposal was given at the Autumn General Meeting, on 10th November, 1948, and details of the proposed amendments were circulated to members in the notice calling that meeting ; they will also be published in the March issue of the *Journal*.

Special Summer Meeting in Norway, 1949

The dates of the Special Summer Meeting of The Iron and Steel Institute, to be held in Norway, are from 28th May to 7th June, 1949. Further details can be found in the issues of the *Journal* for August and September, 1948, and a circular giving full information will be issued shortly.

Changes on the Council

The Honourable **R. G. Lyttelton** has expressed the desire to resign from the position of Honorary Treasurer of the Institute, which he has held since 1942, owing to his other commitments. The Council has accepted Mr. Lyttelton's resignation with regret and nominated him to be a Vice-President. Mr. **James Mitchell**, Vice-President, has accepted the Council's invitation to become Honorary Treasurer. These changes will take effect from 1st January, 1949.

Mr. Lyttelton became a Member of the Institute in 1920, and was elected a Member of Council in 1938. Mr. James Mitchell joined the Institute in 1918, and was elected a Member of Council in 1944 and a Vice-President in 1946.

Sir **John Duncanson**, Honorary Member of Council, has been nominated to be an Honorary Vice-President, as a tribute to his services to the Institute and Industry. Mr. **Edward Senior** has been nominated to be an Honorary Member of Council in succession to Sir John Duncanson in view of his forthcoming appointment as Commercial Director of the British Iron and Steel Federation.

NEWS OF MEMBERS

▶ Mr. E. T. ADAMS has been appointed an Assistant Experimental Officer at the Armament Research Department, Woolwich.

▶ Dr. FRANK ADCOCK has been appointed to take charge of research for the Broken Hill Proprietary Co., Ltd.

▶ Mr. NORMAN S. ANGUS has been appointed metallurgist to the Production Engineering Research Association.

▶ Mr. JOSEF BERGMANN has taken up an appointment as a metallurgist with Messrs. Stewarts and Lloyds, Ltd., of Corby.

▶ Mr. R. R. BRICKNELL is now a metallurgical engineer at Vandervell Products, Ltd., Acton, London, W.3.

▶ Mr. RONALD BUTLER has taken up an appointment as a research metallurgist at the B.S.A. Group Research Centre, Sheffield.

▶ Mr. A. CIBULA has been appointed as an investigator at the British Non-Ferrous Metals Research Association.

▶ Mr. C. J. DANGERFIELD has been awarded the degree of B.Met. and has joined the staff of the British Aluminium Co., Ltd., at Gerrards Cross.

▶ Mr. G. H. DAVIES is now assistant metallurgist at the Panteg Section of Messrs. Richard Thomas and Baldwins, Ltd.

▶ Dr. C. H. DESCH, F.R.S., Past President of the Institute, has been appointed an Honorary Member of the Société des Ingénieurs Civils de France.

▶ Mr. A. T. GREEN, O.B.E., has been appointed Director of Research of the British Ceramic Research Association, Stoke-on-Trent.

▶ Mr. RAYMOND HAYNES has been awarded the George Senior Research Fellowship in Metallurgy and is now engaged in research at Sheffield University.

▶ Colonel C. F. HITCHINS, D.S.O., has been appointed Chairman of the Pearson and Knowles Coal and Iron Co., Ltd., owing to the recent death of Sir Peter Rylands, Bt.

▶ Mr. F. H. HOULT has taken up a position in the Light Castings Department of Messrs. Newton Chambers and Co., Ltd.

▶ Mr. BRINLEY JONES has resigned his position as senior metallurgist in the Metallurgical and Research Department of the English Steel Corporation, Ltd., to join the Climax Molybdenum Company of Europe, Ltd., as Manager.

▶ Sir WILLIAM LARKE, K.B.E., has accepted the office of President of the Institution of Engineers-in-Charge.

▶ Mr. A. E. LEEK has retired from the Board of the Workington Iron and Steel Co., Ltd.

▶ Mr. H. K. LLOYD has been awarded the degree of Ph.D. of Sheffield University. Dr. Lloyd, who was also awarded the Brunton Medal, is now on the metallurgical research staff of the University.

▶ Mr. B. R. NAGAR is now Assistant Director of Inspection (Met.) with the Ministry of Industry and Supply, Burnpur, India.

▶ Mr. R. A. NICHOLLS is taking up a position as a metallurgist at Messrs. Stewarts and Lloyds, Ltd., Department of Research and Technical Development, Bilston, Staffs.

▶ Mr. ARTHUR POOLE has retired from the position of

consulting engineer with the Davy and United Engineering Co., Ltd., Sheffield. Mr. Poole had been with the company since 1906; he became chief engineer in 1931 and consulting engineer in 1947.

▶ Mr. B. CHETWYND TALBOT has been elected a member of the Tees Conservancy Commission.

▶ Mr. A. W. TOWN has been appointed assistant manager of the electric furnace department at Messrs. Hadfields, Ltd.

▶ Mr. R. T. F. WATERS has joined the English Electric Co., Ltd.

▶ Mr. A. B. WINTERBOTTOM is now at the Metallurgist Institutt, Norges Tekniske Hogskole, Trondheim, Norway.

▶ Dr. HAROLD K. WORK has been nominated for the office of President of the American Society for Metals for 1948–49, in succession to Mr. FRANCIS B. FOLEY.

Obituary

The Council regret to record the deaths of the following:

Mr. HORACE FEATONBY, Consultant, and formerly General Works Manager, to Messrs. Dorman, Long and Co., Ltd., on 7th October, 1948, at Montreux, Switzerland.

Mr. JOHN WHITTLE HOLDEN, Production Engineer at The Admiralty, on 1st October, 1948, aged 58.

Mr. FRANK CECIL MANNOX, Managing Director of Murex, Ltd., on 21st October, 1948, aged 49.

Colonel WILLIAM ROUTLEDGE, Consulting Engineer, of Alne, York, on 23rd September, 1948.

Mr. T. J. L. THOMSON, General Manager of Messrs. Bruntons (Musselburgh), Ltd., on 16th October, 1948.

CONTRIBUTORS TO THE JOURNAL

R. M. Cook, B.Sc.(Eng.), A.Met.—Engaged in research on gases in metals at the Research and Development Department, The United Steel Companies, Ltd., Stocksbridge. Mr. Cook was educated at Penistone Grammar School, and joined the staff of The United Steel Companies in 1938 as a junior assistant. He received the Nesthill Medal in 1946, and in the same year was awarded the degree of B.Sc.(Eng.) in metallurgy.

J. E. Truman, A. Met.—On the staff of the Brown-Firth Research Laboratories. Mr. Truman was born in Sheffield, in 1927, and was educated at the Firth Park Grammar School. On leaving school in 1943 he joined the Brown-Firth laboratories. This year he obtained the Associateship in Metallurgy at Sheffield University.

W. Bullough, B.Sc., A.R.I.C.—Research chemist with the British Iron and Steel Research Association at Swansea. Mr. Bullough was educated at Leigh Grammar School and at Wigan Technical College, and in 1938 was awarded a first-class honours degree in chemistry. From 1938 until 1944 he served as an analytical chemist with the Ministry of Supply, and as a research chemist at the Armament Research Department from 1944 until his appointment with B.I.S.R.A. in 1946.

W. H. Bailey, B.Sc. (Eng.).—Engaged on research with the Mechanical Working Division of the British Iron and Steel Research Association. Born at Burton-on-Trent in 1909 and educated at Rossall, Mr. Bailey served his apprenticeship at the Locomotive Works of the London, Midland and Scottish Railway Company, at Derby, and then went to University College, Nottingham, where he obtained the degree of B.Sc.(Eng.) in 1932. In the following year he joined the Central Engineering Department of Messrs. Dorman, Long and Co., Ltd., and was assistant steelworks engineer at their Cleveland Works from 1934 to 1936.

W. Bullough

J. E. Truman

After a year at the Royal Ordnance Factory, Woolwich, Mr. Bailey took up a position in the Technical Department of the British Iron and Steel Federation. From 1947 until July 1948 he was Head of the Rolling-Mill Section of the British Iron and Steel Research Association, and is now at their Metal Flow Research Laboratory, at Sheffield.

H. J. Goldschmidt, M.Sc., A.Inst.P.—Research physicist at the B.S.A. Group Research Centre, Sheffield. Mr. Goldschmidt was born in Berlin, and became a naturalized Englishman in 1941. He studied physics at Göttingen and Leipzig Universities and, after coming to England in 1934, at Manchester, under Sir Lawrence Bragg. He subsequently carried out X-ray investigations on alloy systems with Dr. A. J. Bradley. He obtained the degree of M.Sc. in 1938. In the same year he went to the Research Department of Messrs. Wm. Jessop and Sons, Ltd., where he established and is conducting the X-ray crystallographic section, which is now merged into the B.S.A. Group Research Centre. Besides contributing a number of published papers, Mr. Goldschmidt has translated into English Schenck's "*Physical Chemistry of Steelmaking.*" He serves on the Diffraction Sub-Committee of the British Iron and Steel Research Association.

J. Rankine, B.Sc., D.I.C., M.I.Mech.E.—Development engineer with the Whitehead Iron and Steel Co., Ltd. Mr. Rankine graduated at the Imperial College of Science and Technology in 1929, and received his engineering training with the General Electric Co., Ltd. (at Messrs. Fraser and Chalmers Engineering Works). After a short time with International Combustion Ltd., at Derby, he went to the Bristol Aeroplane Co., Ltd., Engine Division, in charge of the stress office, and remained there until 1946. In that year he joined

R. M. Cook

H. J. Goldschmidt

G. K. Rylands

G. E. Speight

the staff of the British Iron and Steel Research Association and until 1947 was in charge of the experimental rolling-mill laboratory at Sheffield.

G. E. Speight, B.Sc., F.R.I.C., F.I.M.—Chief chemist at the Research and Development Department of the United Steel Companies, Ltd., Stocksbridge. Mr. Speight attended the Firth Park Grammar School, Sheffield, and began his training as a research chemist at the Brown-Firth Laboratories in 1925. He obtained the Associateship in Metallurgy of Sheffield University in 1929 and the degree of B.Sc. of London University in 1936. From 1932 to 1933 he was at the Admiralty Laboratories in Sheffield, and in 1933 joined the staff of the newly formed Central Research Department, under the late Dr. Swinden. Mr. Speight has been associated largely with analytical research, the development and application of methods for gases in metals, and in process-metallurgy research, particularly in relation to iron and steel making. He was appointed to his present position in 1944.

G. K. Rylands, O.B.E.—Managing Director of Messrs. Rylands Brothers, Ltd., Warrington, Lancs. Mr. Rylands was educated at the Royal Naval Colleges at Osborne and Dartmouth. He served in the Royal Navy from 1908 until his retirement in 1919, when he joined the staff of Messrs. Rylands Brothers. In 1929 he was appointed assistant general manager, and in 1936 general manager and Director. He is also a Director of the Whitecross Co., Ltd., and of the Lancashire Steel Corporation, Ltd., and Chairman of Penfold Fencing and Engineering, Ltd. Mr. Rylands has been a Member of Council of the British Iron and Steel Research Association since its formation, and is Chairman of the Mechanical Working Divisional Panel and of the Drawing Committee of that body.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

First Junior Blast-Furnace Conference

The First Junior Blast-Furnace Conference of the British Iron and Steel Research Association was held at Ashorne Hill, near Leamington Spa, on 1st and 2nd November, 1948. The subjects discussed included taphole practice, research work in industry, and iron-ore preparation and blast-furnace practice in the U.S.A.

Thirty-First Steelmaking Conference

The Thirty-First Steelmaking Conference took place on 29th and 30th September, 1948, at Ashorne Hill, near Leamington Spa. Talks were given on "*Hot Topping*," by W. H. Glaisher, on "*The Practical Aspects of Hot Topping*," by R. W. Royston, and on "*The Examination of a Range of Rimmed to Killed Ingots, Made from One Cast of Steel by Varying the Degree of Oxidation during Teeming*," by P. M. Macnair.

Second Chemists' Conference

The Second Chemists' Conference, held at Ashorne Hill, near Leamington Spa, on 6th and 7th October, 1948, was attended by over 100 scientists. The first session was devoted to a consideration of the use of statistical methods in analytical chemistry and promoted considerable discussion. On the second day current researches and completed analytical methods were described and discussed, and an exposition was given of developments in the spectrographic and physico-chemical field.

New Committees

The Plant Engineering Division of the British Iron and Steel Research Association has formed two new committees, with the following terms of reference:

Mechanical Engineering Committee—"To initiate and guide research into mechanical engineering as applicable to the iron and steel industry."

Civil Engineering Committee—"To initiate and guide research into civil and structural engineering as applicable to the iron and steel industry."

Staff

At its meeting on 20th October, 1948, the Council of the British Iron and Steel Research Association received with regret the resignation, as from 31st December, 1948, of Mr. H. A. Bridges, Secretary of the Association. Mr. Bridges decided to take this step after consideration of the fact that the increasing duties which he has had to undertake as a result of the expanding activities of B.I.S.R.A., are having a detrimental effect on his health.

Mr. N. A. Everett will succeed Mr. Bridges and will take up his appointment on 1st December, 1948.

INSTITUTION OF METALLURGISTS

Examination Results

The Examinations of the Institution of Metallurgists were held from 6th to 13th September, 1948, at Birmingham, Glasgow, and London. The following candidates were successful:

Licentiateship—Hoare, Hubert Arthur (Oxford); Lloyd, Raymond Charles (Birmingham); Mills, Raymond (London); Stuttard, Arthur (Burnley).

Associateship—Bergmann, Josef (Corby); Blackburn, Jack (Huddersfield); Brown, James Albert (Wallsend-on-Tyne); Clark,* Edwin Brian (Coventry); Gainsbury, Peter Edward (Harrow); Graham, John Alastair (Slough); Hutchings, Felix Roy (Bedford); Jones,* Gordon Vincent (Llanelly); Kersting, Philip Eric (Corby); Miles, John Joseph (Liverpool); Perry, Edwin Reginald (High Wycombe); Robertson, Thomas (Kilmarnock).

* These candidates successfully completed the Associateship Examination, but their election to the grade of Associate is deferred until they attain the age of 25 years.

NEWS OF SCIENCE AND INDUSTRY

National Foundry College

The new session of the National Foundry College commenced in September and will end in July, 1949. It has been found that some candidates for the full-time

Diploma Course require more preparation, particularly where the major technical colleges are not readily accessible to them. For these, a preliminary course of six months' duration, to be called Part 1 of the Diploma Course, will be arranged to begin in January, 1949. The present Diploma Course will become Part 2, and the intervening period between the end of Part 1, in June, and the beginning of Part 2, in the following September, can be spent in acquiring foundry experience.

Further details of the two courses may be obtained from the Head of the National Foundry College at the Technical College, Wolverhampton.

George Stephenson's Cottage at Wylam

As a result of an appeal, issued by the President of the North-East Coast Institution of Engineers and Shipbuilders, it has been possible to purchase the cottage at Wylam, Northumberland, in which George Stephenson was born. In due course the cottage will be handed over to the National Trust for preservation.

The original appeal was for £1200, but it is now considered desirable to increase the target to £1500, so that adequate funds for maintenance will be available. Further donations to the fund are invited from both individuals and firms.

Memoranda

B.I.S.C. (Ore), Ltd., have changed their address from Granite House, Cannon Street, London, E.C.4, to 9, St. Helen's Place, London, E.C.3 (telephone: London Wall 6661).

The Broken Hill Proprietary Coy., Ltd., Ibex House, Minories, London, E.C.3, have changed their address to Hanover House, 14, Hanover Square, London, W.1 (telephone: Ambassador 3221/2).

MEMOIRS

The Rt. Hon. Viscount **Greenwood,** P.C., K.C., President of the Pilgrims Society, Chairman of the Anglo-Egyptian Chamber of Commerce, and Chairman of Messrs. Dorman, Long and Co., Ltd., died at his home in London on 10th September, 1948. Born at Whitby, in Ontario, Canada, he was of English descent and his mother was a member of one of the families that went over to Canada from the new United States after the American Revolution. He was a B.A. of Toronto University, and the honorary degree of LL.D. was conferred upon him in 1938.

At the age of sixteen Lord Greenwood enlisted in the Canadian Militia, serving as a lieutenant until 1895, when he came to England and became a student, and later a Barrister, of Gray's Inn. He was made a K.C. in 1906.

He became Member of Parliament for York in 1906 and for Sunderland in 1910. As one of the Members of the County of Durham, he became familiar with, and took the greatest interest in, the coal, iron, and steel trade of that County. He was elected the Member for Walthamstow in 1924 and from that time he took a leading part in advocating protection for the iron and steel industry. He was created a baronet in 1915. In 1920 he became the last Chief Secretary for Ireland, with a seat in the Cabinet, and was a signatory of the Irish Treaty in 1922.

Lord Greenwood had a wide experience in business and in conducting public companies. He was made Chairman of Dorman, Long and Co., Ltd., in 1934. He became a Member of The Iron and Steel Institute in 1939.

Sir **William Peter Rylands,** Bt., J.P., a Past-President of The Iron and Steel Institute, and Managing Director since 1898 of the firm of Messrs. Rylands Brothers, Ltd., of Warrington, died on 22nd October, 1948, at his home, near Warrington. A son of the late Peter Rylands, M.P., he was educated at Charterhouse and at Trinity College, Cambridge. He was called to the Bar in 1894 and specialized in patent law until the death of a cousin four years later caused him to take over the managing directorship of Rylands Brothers, Ltd. At first he knew nothing of the business, but he studied its commercial and technical problems to such effect that he extended its scope by adding steel and coal to its interests and built up the concern until it was four or five times as large as when he assumed control.

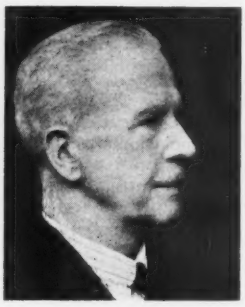
Sir Peter was elected President of The Iron and Steel Wire Manufacturers' Association in 1900, of the Federation of British Industries from 1919 to 1921, and of the National Federation of Iron and Steel Manufacturers in 1930. He was High Sheriff of Cheshire from 1935 to 1936 and was created a Baronet in 1939.

In 1901 he joined The Iron and Steel Institute, becoming a Member of Council in 1913 and President for the period 1926–27.

Sir **Peter Boswell Brown,** an Honorary Vice-President of The Iron and Steel Institute, and for many years associated with Messrs. Hadfields, Ltd., died on 12th October, 1948. He was born at Greenock in 1866 and was educated at Greenock, Woolwich, and at Sheffield University. His apprenticeship was served with Messrs. Easton and Anderson, of Erith.

In 1888, as draughtsman and assistant manager, Sir Peter began his long and distinguished career with Messrs. Hadfields, Ltd. The company then employed 400 men; since that time he played a large part in the firm's developments. Amongst these may be mentioned the development for industrial purposes of Hadfield's 13% manganese steel; the designing and patenting of the first solid cast manganese-steel switch for tramways; and the Hadfield system for the manufacture of armour-piercing projectiles. As works manager he was largely responsible for the East Hecla Works, at Tinsley, and later took over the management of the Hecla and the East Hecla Works. He was invited to join the Board in 1909, was appointed Managing Director in 1917, Deputy Chairman in 1930, and Chairman of the Company in 1940, on the death of Sir Robert Hadfield. He retired from active business in 1945.

Sir Peter was knighted in 1945. He was a member of the Institution of Civil Engineers, and of many other scientific and technical societies. He was elected a Member of The Iron and Steel Institute in 1899, becoming a Member of Council in 1933, a Vice-President in 1943, and an Honorary Vice-President in 1945.



Sir Peter Boswell Brown

Sir W. Peter Rylands, Bt.

Sir **Clifford Copland Paterson,** O.B.E., F.R.S., Founder and Director of the Research Laboratories of the General Electric Company, Ltd., at Wembley, died on 26th July, 1948, at the age of 68. Sir Clifford Paterson was born in London in 1879 and was educated at Mill Hill School. He received his technical training at Finsbury Technical College and at Faraday House. From 1901 to 1919 he was at the National Physical Laboratory, where he was responsible for the photometric and electrotechnical departments. Joining the General Electric Company in 1919, to establish and direct the Research Laboratories at Wembley, he built up an organization which, during the war, was engaged largely on radar development, and now has a staff of more than a thousand.

Sir Clifford was a Past-President of the Institution of Electrical Engineers, the Institute of Physics, and other bodies. He became a Member of The Iron and Steel Institute in 1928.

John Whittle Holden died on 1st October, 1948, aged 58. He was educated at New College, Harrogate, and at Manchester Grammar School, and his practical training was gained with various companies in Lancashire. During the course of his career he was associated with a number of firms. In 1912 he was engaged upon locomotive repairs with the Great Central Railway, at Gorton. Two years later he was appointed superintendent in charge of plant erection at home and abroad, until 1916, when he transferred to the Ministry of Munitions as assistant engineer in the armament production department, and later in the finance department. In 1918 he joined the staff of The Admiralty as chief technical assistant and in 1923 became deputy principal of the Technical Branch. After sixteen years with The Admiralty he took up a position as engineer-controller and sales manager with the Quasi Arc Welding Co., Ltd., which was later absorbed by the British Oxygen Co., Ltd. He left this firm in 1939 to become assistant works superintendent, and later works superintendent, at the English Electric Co., Ltd., Stafford, rejoining The Admiralty in 1941 as a production engineer.

Mr. Holden was an Associate Member of the Institution of Mechanical Engineers, and was elected a Member of The Iron and Steel Institute in 1925.

Frederick Felix Gordon, a Joint Managing Director of Messrs. Spear and Jackson, Ltd., Sheffield, died on 22nd June, 1948. Born in Birmingham in 1887, Mr. Gordon came to Sheffield in his early childhood and began his career there as an office boy. His early interest in metallurgy led him to join Messrs. W. T. Beesley, Ltd., where he received several years' experience in the laboratory. He also studied at evening classes at Sheffield University, as a result of which he was awarded the Associateship in Metallurgy.

In 1912 he joined Messrs. Spear and Jackson, Ltd., and remained with that firm until his death. His first appointment was as Manager of the Steel Department; in 1916 he put down the first Greaves-Etchells furnace to be built, and was the first man to make high-speed steel in an electric furnace. His many inventions include a process for making hollow-drill steel; he installed a new factory at the United Steels Company, in Vereeniging, for the manufacture of this steel. During the recent World War he was responsible for the manufacture of 1¼ million armour plates for tanks, bren-gun carriers, and aircraft.

William Hutton Cathcart, formerly Metallurgical Manager of Messrs. Lobnitz and Co., Ltd., Engineers and Shipbuilders, of Renfrew, Scotland, died on 16th September, 1948. Born in Glasgow, in 1872, and educated at the Gallatown Public School, Kirkcaldy, Mr. Cathcart served his apprenticeship as a blacksmith, subsequently working with several engineering and shipbuilding firms in Fifeshire and Glasgow. He studied metallurgy at the Royal Technical College, Glasgow. In 1900 he was appointed foreman smith at the Hyde Park Locomotive Works (later the North British Locomotive Co., Ltd.), Glasgow, and held this position until 1916, when he became manager of the Marine Shell Forge of the North British Locomotive Co., Ltd. He joined Messrs. Lobnitz and Co., Ltd., as metallurgical manager in 1919 and remained in that position until his retirement in 1944.

Mr. Cathcart was President of the Associated Foremen Smiths of Scotland for the period 1912–1914, and was awarded the Gold Medal and Freedom of the Worshipful Company of Blacksmiths in 1920, receiving the Freedom of the City of London in 1921. He was the author of many papers on iron and steel and of the book "*The Value of Science in the Smithy and Forge.*"

Andrew C. Bernard, Manager of the Carron Company, Carron, died on 26th August, 1948, aged fifty-five. Mr. Bernard served an engineering apprenticeship with Messrs. Douglas and Grant, of Dunnikier Foundry, Kirkcaldy, and received his technical training at the Heriot-Watt College, Edinburgh, where he was Bronze Medallist for two successive years. In 1920 he became chief draughtsman at the Blochairn Works of the Steel Company of Scotland, Ltd., Glasgow, and later was appointed chief engineer. He joined the Carron Company in 1932 as their superintending engineer and three years later was appointed engineering works manager. In 1939 he returned to the Blochairn Steel Works, as manager, but in 1942 re-entered the service of the Carron Company as chief works manager. The following year he was appointed assistant manager, and in May, 1944, he succeeded Mr. George Pate as manager.

Thomas Oswald Lewis, a Joint Assistant Managing Director of the Steel Company of Wales, Ltd., died after a short illness, on the 28th September, 1948, at his home at Llanelly.

Mr. Lewis was born at Lydney, 65 years ago, and entered the service of Messrs. Richard Thomas and Co., Ltd., when 15 years old. He became mill superintendent at Lydney and later was appointed manager at the Edlogan Works at Pontnewydd. Later he was transferred to act as general manager of a number of tinplate works in the Llanelly area, and in due course the control of a large steelworks was added to his responsibility.

In 1931, Mr. Lewis was made a Director of the firm. When the new Steel Company of Wales was formed in October of 1947, he was appointed to the Directorate and was made General Manager of the Company's large tinplate works. He was also directing the construction of the very modern cold-reduction plant at Llanelly.

Mr. Lewis was a member of the Advisory Committee for Technical Education in Wales and of the various research committees co-operating with the University College of Swansea. He was elected, in 1939, to the Chairmanship of the Employers' Side of the Welsh Tinplate Joint Industrial Council, and became a Member of The Iron and Steel Institute in 1918.

T. J. L. Thomson, General Manager of Messrs. Bruntons (Musselburgh), Ltd., died on 16th October, 1948. Mr. Thomson was born in 1905 and was educated at Rossall School. After several years at Manvers Main Collieres he was awarded his Manager's Certificate (First Class) in 1930, and remained with that company until his appointment, in 1936, as assistant to the Managing

Director of Messrs. F. R. Simpson and Company. He became general manager of Messrs. Bruntons in 1946.

Frank Cecil Mannox, Managing Director of Murex, Ltd., died on 21st October, 1948, at the age of 49 years. Mr. Mannox was educated at King Edward's School, Birmingham, and after serving in the first World War, he joined Messrs. Elliott's Metal Works (later absorbed by I.C.I., Ltd.) He subsequently held positions with the Imperial Chemical Industries, Ltd., Metals Division, and with Messrs. J. Bibby, Sons, and Co., Ltd., of Liverpool.

During the recent war he was loaned to Murex, Ltd., taking over the managing directorship in 1942. He subsequently contributed largely to the guidance of the company through its immediate post-war problems, and played a large part in strengthening its organization and in the development and expansion of its future activities. He became a Member of The Iron and Steel Institute in 1944.

Horace Featonby, who was for many years associated with the firm of Messrs. Dorman, Long and Co., Ltd., died on 7th October, 1948. Mr. Featonby commenced his training as a draughtsman at the works of Messrs. Cochrane and Co., Ltd., of Middlesbrough, and after a period with the Tees-Side Bridge and Engineering Co., Ltd., as a constructional draughtsman, he transferred to Messrs. Dorman, Long and Co., Ltd. In 1905 he went to America to work with the Canadian Bridge Company, and the Dominion Bridge Company of America, returning to this country four years later to take up another appointment in the drawing office of Dorman, Long and Co., Ltd.

Mr. Featonby was jointly responsible for the design of the Redcar steelplant buildings, and in 1917 was transferred to the Redcar Works as chief draughtsman, which position he held until 1930 when he took charge of the contract for the building of the South African Steelworks at Pretoria. After some time in South Africa he returned in 1936 to become assistant general manager at the Redcar Works, and general works manager in 1937.

Mr. Featonby retired from the management of the Works in 1943 owing to ill-health, but retained an interest in the company as a consultant. He joined The Iron and Steel Institute in 1937, and in 1938 was elected a Member of Council of the Cleveland Institution of Engineers.

Colonel **William Routledge,** Consulting Engineer, of Alne, York, died on 23rd September, 1948. He had been a Member of The Iron and Steel Institute for forty-five years. He was educated at Wycliffe College, and after a short period with the Tredegar Iron and Coal Co., Ltd., he trained as an engineer with a firm in Chesterfield and with the Westinghouse Electrical Company in Pittsburgh. On returning to this country in 1902, he served for three years on the staff of the British Westinghouse Company, at Manchester, after which he transferred to the Ebbw Vale Iron and Coal Co., Ltd., as works engineer.

In 1912 Colonel Routledge was appointed chief engineer to Messrs. Bolckow Vaughan and Co., Ltd., and held that position until 1937. He then joined the International Construction Company as resident engineer at the Steel Corporation of Bengal. Four years later he returned to this country to become general manager at the Stanton Ironworks Co., Ltd., where he remained until his retirement from executive work in 1945, continuing his association with industry as a consulting engineer.

Colonel Routledge was a Past-President of the Cleveland Institution of Engineers.

DIARY

6th Jan.—LEEDS METALLURGICAL SOCIETY—"*Modern Techniques in Non-Destructive Testing,*" by E. J. Vaughan—Chemistry Department, The University, Leeds, 7.0 P.M.

6th Jan.—MIDLAND METALLURGICAL SOCIETIES—"*Metals in Instruments,*" by E. H. Bucknall—James Watt Institute, Great Charles Street, Birmingham, 6.30 P.M.

6th Jan. — LIVERPOOL METALLURGICAL SOCIETY — "*The Steelmaking Process,*" by Sir Charles F. Goodeve, O.B.E., F.R.S.

8th Jan.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY—"*Plant Developments in the Aluminium Industry,*" by B. N. H. Thornely—Newport Technical College, 6.30 P.M.

8th Jan.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—"*The Jointing of Metals,*" by D. F. Hewitt—Swansea, 6.30 P.M.

10th Jan.—SOCIETY OF INSTRUMENT TECHNOLOGY—"*Recent Developments in the Instrumentation of Open-Hearth Furnaces,*" by J. H. Chesters—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 P.M.

10th Jan.—CLEVELAND INSTITUTION OF ENGINEERS—"*Wheels within Wheels*"—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 P.M.

11th Jan.—INSTITUTE OF MARINE ENGINEERS—"*Methods of Non-Destructive Testing of Large Marine Forgings and Castings,*" by J. Rhodes, T. H. Arnold, and J. R. Rait—85, The Minories, London, E.C.3, 5.30 P.M.

12th Jan.—INSTITUTION OF PRODUCTION ENGINEERS (Sheffield Section, Joint Meeting with the Iron and Steel Engineers Group)—"*The Steel Company of Wales. Developments at Port Talbot,*" by W. F. Cartwright—Royal Victoria Station Hotel, Sheffield, 6.30 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the November, 1948, issue of the *Journal*, p. 320.)

TRANSLATIONS AVAILABLE

No. 364 (German). P. WOLF: "The Development of the Blast-Furnace Profile in Different Countries." (*Stahl und Eisen*, 1947, vol. 66–67, Dec. 4, pp. 411–416).

No. 365 (German). K. GUTHMANN: "The Rate of Driving of Blast-Furnaces." (*Stahl und Eisen*, 1947, vol. 66–67, Dec. 4, pp. 425–427).

No. 366 (German). F. KOFLER and G. SCHEFELS: "Flow Processes in the Hearth of Open-Hearth Furnaces." (*Stahl und Eisen*, 1933, vol. 53, Feb. 16, pp. 162–167).

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the Series.

Increase of Charges

As previously announced, the price of translations has been increased, as from 1st July, 1948, to £1 for one copy of any translation in the Series, and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance.

Translations in the Series are not available on loan from the Joint Library.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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ORES—MINING AND TREATMENT

South Agnew Stripping Scheme Unique in Mesabi Practice. E. S. Mollard and H. E. Reese. (Engineering and Mining Journal, 1948, vol. 149, Aug., pp. 70–74). A description is given of the equipment at the South Agnew property on the Mesabi range for removing and disposing the overburden. This equipment includes a mammoth walking dragline operating a 25-cu. yard bucket scraper, a conveyor system 5851 ft. long, screening plant, and stacker 245 ft. long. The estimated digging capacity is 1010 cu. yards/hr.—R. A. R.

Ore Discharging. G. T. Shoosmith. (Journal of The Iron and Steel Institute, 1948, vol. 160, Sept., pp. 75–84).

Rationalization in Swedish Iron-Ore Dressing. S. Mörtsell. (Iron and Steel Institute, 1948, Translation Series, No. 351). This is an English translation of a paper which appeared in Jernkontorets Annaler, 1946, vol. 130, No. 9, pp. 369–460 (*see* Journ. I. and S.I., 1946, No. II, p. 125A).—R. A. R.

Full-Scale Trials of the Magnetizing Roasting of Iron Sandstone and Iron Ores. W. Luyken. (Kaiser-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 105–110). After describing the plant which was erected at Praschkau in 1942 for full-scale trials of the magnetizing-roasting of the iron sandstones of Upper Silesia, the author presents some of the results obtained and discusses the economic aspects of the process. The ores contained about 14–18% of iron and concentrates with 44–50% were obtained, the recovery being about 76%. With a daily rotary-kiln throughput of 4·8 ton/cu. m. kiln volume the consumption of producer gas (calorific value 950 kg.cal./cu. m.) was 185 cu. m./ton of ore. The process was also successfully applied to produce a concentrate containing iron 50%, manganese 3%, and silica 5% from hitherto unusable slimes arising from the flotation of a carbonaceous spathic iron ore.—R. A. R.

FUEL—PREPARATION, PROPERTIES, AND USES

The Fuel Problem in Russian Metallurgy and New Technological Coking Methods. N. P. Chizhevskiy. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Techniques, 1947, No. 10, pp. 1323–1327).

Chemistry and Physics of Combustion, Gasification, and Metallurgical Processes. W. Gumz. (Bergbau-Archiv, 1947, vol. 7, pp. 96–111: British Abstracts, BI, 1948, June, col. 222). The chemical, physical, and thermodynamical bases of combustion, etc., are discussed in detail theoretically, methods of calculation of combustion temperatures and equilibrium constants are given, and the extent to which equilibrium will be attained in gas producers and furnaces, is examined. The metallurgical process of the blast-furnace is treated thermodynamically and a new interpretation of the results is suggested. Among the reactions considered are the following: $C + O_2 = CO_2$, $CO_2 + C = 2CO$, $H_2O + C = H_2 + CO$, $2H_2 + C = CH_4$, $MnO + CO = Mn + CO_2$, and the reactions of carbon monoxide and hydrogen with FeO, Fe_2O_3 and Fe_3O_4.

Electricity from Waste Gas. (Power & Works Engineering, 1948, vol. 43, Sept., pp. 273–276). **Power Generation with Blast Furnace Gas.** (Steam Engineer, 1948, vol. 17, July, pp. 374–380). An illustrated description is given of the waste-gas-fired boilers, engines, and generating sets at the ironworks of the Renishaw Iron Co., Ltd., near Sheffield. The boiler installation consists of four 5-drum Stirling watertube boilers and six Lancashire boilers.—R. A. R.

Waste Heat Boilers. (Engineering and Boiler House Review, 1948, vol. 63, July, pp. 201–204). A number of waste-heat boiler installations, including the Cochran, Clarkson, and Spencer-Bonecourt types, are described with notes on the particular conditions for which each is suitable.—R. A. R.

Recuperation Improves Furnace Efficiency and Operation. F. D. Hazen. (Industrial Heating, 1948, vol. 15, May, pp. 786–796). Fuel savings which can be obtained by using recuperators to preheat air for combustion are discussed and series of curves giving the saving under various conditions for rich and lean fuels are presented. A metallic recuperator is described.—R. A. R.

A Note on the True Density, Chemical Composition, and Structure of Coals and Carbonized Coals. Rosalind E. Franklin. (Fuel, 1948, vol. 27, May–June, pp. 46–49).

Modern Mechanized Mining and Coal Preparation for Metallurgical Coal. J. Griffen. (American Iron and Steel Institute, May 26–27, 1948, Preprint). The results obtained with mobile loading equipment in American coal mines and the performance of some coal preparation plants are reviewed.—R. A. R.

Movable Wall Oven. Its Use in Coke-Oven Plant Operations. J. G. Sweeney. (Gas, 1947, vol 23, Jan., p. 38: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 5–6, p. 104). A description is given of a small coke-oven with a movable wall which enables low-quality coal to be used. Advantages over ordinary coke ovens are discussed.

Proper Sizing, Screening and Preparation of Blast Furnace Coke. D. P. Cromwell and C. A. Covington. (American Iron and Steel Institute, May 26–27, 1948, Preprint). Coke sampling and the A.S.T.M. tumbler test for blast-furnace coke as applied at the Campbell Works of the Youngstown

Sheet and Tube Co. are described and the improvements in blast-furnace practice resulting from proper preparation and control of the coke are discussed.—R. A. R.

The Woodall-Duckham Laboratories. (Coke and Gas, 1948, vol. 10, July, pp. 245–250). An illustrated description is given of the laboratories of the Woodall-Duckham Company at Croydon, with a review of some of the investigations on coal, tar, benzole, and refractory materials which have been carried out.—R. A. R.

Survey of Foundry Coke Characteristics. D. E. Krause and H. W. Lownie, jun. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 337–350). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 142.

Effect of Coke Quality on Cupola Melting. D. E. Krause. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 620–625). *See* Journ. I. and S.I., 1948, vol. 158, Jan., p. 148.

Gas for Steel Making. A. Q. Smith. (Industrial Gas, 1948, vol. 26, June, pp. 5–7, 29). The practice at Atlanta Steel Co., Atlanta, Ga., is described.

Industrial Oil Burners. G. M. Davies. (Journal of the Society of Engineers, 1948, vol. 39, Apr.–June, pp. 81–89). Five types of oil burner are briefly described and discussed, namely: (1) Horizontal rotary; (2) low-pressure air atomizing; (3) high-pressure air and steam atomizing; (4) aspirating or vacuum-pressure atomizing; and (5) mechanical-pressure atomizing.—R. A. R.

Economic Utilization of Fuel Oil in Boiler and Industrial Furnaces. A. Pearce. (Institute of Petroleum Review, 1948, vol. 2, June, pp. 170–173; July, pp. 202–207; Aug., pp. 244–248). In the first part the general properties of fuel oil and the combustion of oil are dealt with; in the second part several types of atomizing and rotary oil burners are described with diagrams; the third part deals with the design of oil-fired furnaces, heat-transfer calculations, comparison of results with coal and oil firing, and costs of oil burning. R. A. R.

TEMPERATURE MEASUREMENT AND CONTROL

Automatic Control of a Laboratory Furnace Having "Kryptol" Heating Elements. E. Bonnier and G. Weiss. (Verres et Réfractaires, 1948, vol. 2, Apr., pp. 91–94). It is claimed that variations of temperature at 1500° C. may be reduced to ± 4° to 5° C.

Determination of Molten Metal Temperatures. G. Vennerholm and L. C. Tate. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 500–509). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 140.

A Multi-Point-Furnace Control Panel. C. L. M. Cottrell. (Metallurgia, 1948, vol. 38, July, pp. 132–134). A description is given of the methods adopted in the British Welding Research Association's metallurgical laboratories to control a number of furnaces by means of an electrically operated control panel. A small number of controlling and recording instruments are grouped together, each one of which can be attached to the furnace which it is desired to use.—P. W.

Furnace Pressure Control in Relation to Performance. C. H. Stone. (Metallurgia, 1948, vol. 38, July, pp. 161–164). The importance of furnace-pressure control in relation to the performance of open-hearth and other industrial furnaces is discussed. The implications of the term "furnace pressure" are considered in detail.—P. W.

The Fundamentals of Pyrometry. Parts I and II. W. H. Steinkamp. (Finish, 1948, June, pp. 23, 26, 73, 76, 78; July, pp. 23, 26, 64, 66, 68: Bulletin and Foundry Abstracts of the British Cast Iron Research Association, 1948, vol. 9, Sept., p. 268).

An Experimental Furnace for the Investigation of Open-Hearth-Furnace Combustion Problems. Part IV—The Study of Roof Temperatures. J. H. Cook and A. H. Leckie. (Journal of The Iron and Steel Institute, 1948, vol. 160, Sept., pp. 46–56).

Thermal Measuring Instruments. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1672: H.M. Stationery Office). This is a report on visits to 37 German instrument manufacturers and technical high schools to obtain information on: (1) Instruments for temperature measurement and control; (2) instruments for air and gas flow under pressure, and humidity measurements; and (3) research in progress, such as the calculation of the specific heat of gases.—R. A. R.

REFRACTORY MATERIALS

Substitutes for Silica-Brick Linings in Bessemer Converters from Local Raw Materials of Mid-Asia. V. Ya. Kozlov. (Trudy Khar'kovskogo Khimio-Teknologicheskogo Instituta im S. M. Kirova, 1944, vol. 4, pp. 113–115: Chemical Abstracts, 1948, vol. 42, Aug. 20, col. 6071).

Phase Diagrams for Ceramists. F. P. Hall. and H. Insley. (Journal of the American Ceramic Society, 1947, Nov., Special Issue). Phase diagrams are discussed and those of interest to ceramists are compiled giving the reference to original source. Over 420 phase diagrams, 26 liquidus curves, 16 diagrams showing the optical properties of miscellaneous crystalline systems, and 9 temperature-deformation diagrams are included in this compilation.—R. F. F.

Permeability Data on American Refractories. D. O. McCreight. (American Ceramic Society Bulletin, 1948, vol. 27, July 15, pp. 257–262). Permeability determinations were made by measuring the flow of air under a definite pressure through a refractory brick. After reviewing briefly the work done by previous investigators the author describes the apparatus and methods used. Tables give results for various types of fireclay, high-alumina, silica, magnesite, chrome, fosterite, and insulating brick, and show also the effect of firing temperature on the permeability of a high-duty fireclay brick.—R. F. F.

Super-Duty Silica Bricks. F. Singer. (International Ceramic Congress, Maastricht, Holland, Sept. 14, 1948: Iron and Coal Trades Review, 1948, vol. 157, Sept. 17, pp. 611–615). An account is given of the life and failure of refractories used in open-hearth furnace roofs and the improvement obtained when high-duty silica bricks are used for this purpose. Reference is made to the work of various investigators and a short bibliography is appended.—J. C. R.

Relation between Some Properties of Refractory Silicate Systems and Their Compositions. A. I. Avgustinik. (Ogneupory, 1947, vol. 12, No. 4, pp. 179–188: American Ceramic Abstracts, 1948, vol. 31, Aug. 1, p. 179).

Superstability of New Dense Corundum Refractories. N. V. Solomin. (Stekol'naya i Keramicheskaya Promyshlennost, 1947, No. 4, pp. 20–22: American Ceramic Abstracts, 1948, vol. 31, Aug. 1, p. 179). Tests were conducted with the two newest dense corundum refractories made in Russia, "vitreocorundum" and "thermitocorundum." They have a resistance 20 to 40 times greater than that of high-quality grog refractories and electromelted mullite to the action of a molten sulphate charge (85% Na_2SO_4 + 15% $CaSO_4$) at 1350° and 1450° C. in the presence of reducing agents. These new refractories also have a higher resistance to the action of molten glass than high-quality grog.

Chemical and Mineralogical Changes in Stack and Hearth Refractories of a Blast Furnace. L. H. Van Vlack. (Journal of the American Ceramic Society, 1948, vol. 31, Aug. 1, pp. 220–235). Refractory samples were removed from a blast-furnace, blown out after producing 2,300,000 tons of iron (none of which was high manganese iron) and were analysed for chemical and mineralogical changes. Results of these tests are given in comprehensive tables, and these changes and their probable effects on refractory life are discussed. On the basis of these findings, suggestions are made regarding blast-furnace refractory practice.—R. F. F.

Refractories, Use with Oxygen Firing Still Offers Problems to Steelmakers. (Brick and Clay Record, 1948, vol. 112, June, pp. 66, 68).

Special Refractories for Metal Melting. W. H. Henson. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 395–411). *See* Journ. I and S.I., 1947, vol. 157, Oct., p. 291.

Refractory Materials in the Foundry Industry. G. R. Rigby and A. T. Green. (Institute of British Foundrymen, June 8–11, 1948, Paper No. 906). The authors discuss the factors that affect the life of refractory linings used in the cupola, ladle, and side-blown converter. After referring to the effect of chemical constitution of the linings and the technique of ramming, the action of ferrous oxide slags on acid linings is examined and details of tests devised to study the mechanism of slag attack, are given. The use of basic refractories to combat slag attack is noted.—J. C. R.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Modernisation in Progress at the Works of Consett Iron Company, Limited. A. McLeod. (Iron and Coal Trades Review, 1948, vol. 157, Aug. 27, pp. 447–455; Sept. 3, pp. 507–515). A detailed account is presented of the extensive plant renewal and modernization in progress at the works of Consett Iron Company, Ltd. The first part deals with the coke-ovens, ore-preparation and blast-furnace plant, the steelworks and new power plant. The second deals with the boiler equipment and combustion system, electrical arrangements, turbo-blowers and cooling tower. A note is appended on the activities of a subsidiary company, Jarrow Steel Company, Limited.—J. C. R.

Economics of Ferrous Smelting. P. E. Cavanagh. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, July, pp. 20–23, 37, 42). A study was made by the Ontario Research Foundation of methods of smelting iron ores to determine (*a*) whether any known process would be particularly suitable for present and future Canadian conditions, and (*b*) whether any new process would assist in solving the present scrap shortage. There is no alternative to the blast-furnace in Canada if a production rate of more than 600 tons/day of iron is desired. A shipment of Steep Rock ore was sent to Sweden and put through the Wiberg furnace. This ore contains 8% water of crystallization which is driven off in the preheating zone leaving the ore in a porous state ideal for gaseous reduction. Excellent results were obtained with higher production rates than any other ore tried in this furnace.

Small electric smelting installations are particularly attractive in some locations in Canada. In other locations the low-shaft oxygen furnace operating under high pressure could produce a high tonnage of iron per unit using smaller quantities of cheaper coke per ton of iron.—R. A. R.

New Blast Furnace Bosh Cooling Plate. (Iron and Coal Trades Review, 1948, vol. 157, Aug. 27, p. 470). A brief illustrated description is given of a blast-furnace bosh cooling plate, invented by James Dale, where the baffles are arranged lengthwise instead of crosswise and the plate can be fed or discharged from either side.—J. C. R.

The Possibilities of Influencing the Oxidation Zone of the Blast-Furnace. (Iron and Steel Institute, 1948, Translation Series, No. 355). This is an English translation of a paper which appeared in Stahl und Eisen, 1947, vol. 66–67, Aug. 14, pp. 277–284 (*see* Journ. I. and S.I., 1948, vol. 158, Mar., p. 395).—R. A. R.

Blast Furnace Metal. Desiliconization by Means of Mill Scale. E. F. Brown. (Cleveland Institution of Engineers and Lincolnshire Iron and Steel Institute: Iron and Steel, 1948, vol. 21, Aug., pp. 367–371; Sept., pp. 409–410). Practical experiments were made on the desiliconization of blast-furnace metal by adding millscale to the metal in the runner during casting, whereby the average silicon content of 1·27% was reduced by 0·34%. The experimental methods tried are described and the data obtained are correlated. The results are compared with those of other investigators.—J. C. R.

Frequent Determination of Hydrogen in Blast-Furnace Gas. Boissin. (Revue de l'Industrie Minérale, 1948, Aug., pp. 549–559). Methods for the rapid determination of hydrogen in blast-furnace gas, the apparatus and the results obtained are described. The main purpose of the many determinations described in this paper, was to discover water leaks from the tuyeres which are indicated by sudden variations in the hydrogen content of the blast-furnace gas. Methods of compensating humidity, introduced into the blast-furnace, by varying the temperature of the blast, are discussed. R. F. F.

Immiscibility Phenomena in Ferrous-Oxide/Sodium-Phosphate Slags. W. Oelsen and H. Wiemer. (Iron and Steel Institute, 1948, Translation Series, No. 350). This is an English translation of a paper which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1942, vol. 24, No. 13, pp. 167–210 (*see* Journ. I. and S.I., 1945, No. II, p. 179A).—R. A. R.

PRODUCTION OF STEEL

Steel Making, Heating and Heat-Treating Furnaces at the Kaiser Fontana Plant. (Industrial Heating, 1948, vol. 15, Mar., pp. 386–398, 414; July, pp. 1114–1120, 1158). Illustrated descriptions are given of the coke ovens, blast-furnaces, open-hearth shop, electric arc furnaces, and the reheating and heat-treatment furnaces at the Fontana plant of the Kaiser Co., Inc.—R. A. R.

Production of Carbon and Alloy Steels by the Side Blown Converter Process. F. Cousans. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 34–38). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 468.

The Metallurgy of the Basic-Bessemer Process. W. Oelsen and H. Maetz. (Kaiser-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 111–117). The authors discuss the characteristic of the mineral and alkali phosphates, *i.e.*, that they are practically immiscible with ferrous oxide in a melt, and then consider the significance of this in dephosphorization reactions. The effect of silicon on the dephosphorization reaction can be deduced from the observation that, in phosphate slags, it narrows the miscibility gap and actually closes it at 15% SiO_2. The powerful dephosphorizing action of the alkali oxides is also studied by slag constitution diagrams and laboratory tests. The results and conclusions are applied to the study of the basic-Bessemer process.—R. A. R.

An Experimental Furnace for the Investigation of Open-Hearth-Furnace Combustion Problems. Part III—Studies with the Maerz Port and Various Modifications Thereof. J. F. Allen, J. H. Cook, and G. Fenton. (Journal of The Iron and Steel Institute, 1948, vol. 160, Sept., pp. 37–45).

Study of Two Melts of Steel in the Siemens-Martin Basic Furnace. D. L. Schwartsman and H. J. Ceccantini. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Apr., pp. 211–236: [Abstract] Metals Review, 1948, vol. 21, Aug., p. 4). Conditions necessary for the oxidation of carbon, silicon, manganese, sulphur, and phosphorus are established for four types of slags.

Diffusion Phenomena in Manufacture of Steel by the Basic Electric Arc-Furnace Process. R. Zoja. (Ricerca Scientifica e Ricostruzione, 1947, vol. 17, pp. 935–936: British Abstracts BI, 1948, July, col. 320). Analysis of the decarburization curves obtained in the refining of steel in the basic arc furnace indicates that, in the first stage of the process, partial dissociation of the iron compounds in the slag occurs to produce an internal homogeneous equilibrium between free FeO and undissociated iron compounds; some of the FeO then diffuses into the molten steel and this oxidizes (probably incompletely) the carbon in the iron with evolution of CO. Possible retardation of the process because of diffusion effects is discussed.

FOUNDRY PRACTICE

Some Fundamental Problems in Foundry Planning. J. Drachmann. (Institute of British Foundrymen, June 8–11, 1948, Paper No. 910). Some of the main problems that arise in foundry planning are discussed. Two principles must always be borne in mind. First, the principle of total load which means that the total volume of orders on hand must be taken into account when promising delivery dates. Secondly, the principle of margin where due allowance must be made for unexpected delays due to illness, shortage of materials, etc.—J. C. R.

Mechanized Foundry Design and Operating Phases. C. O. Bartlett. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 546–557). Factors which affect the mechanization of foundries, and the equipment commonly used are discussed.—R. F. F.

Designing Castings in Gray Iron. C. O. Burgess. (Foundry, 1948, vol. 76, Sept., pp. 100–101, 224, 226). Examples are given of poor and good design of castings so as to indicate the principles to be followed in designing castings.—R. A. R.

Technological Principles of Casting Design. V. M. Shestopal. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 619–625). *See* Journ. I. and S.I., 1946, No. I, p. 20A.

The Technological Principles of Casting Design. (Machinery Lloyd, 1948, vol. 22, May 8, pp. 82–85: [Abstract] PERA Bulletin, 1948, vol. 1, Aug., p. 599). A number of examples are given of points exemplifying good and bad casting design.

Present Day Problems in the Operation of Austrian Foundries. L. Schmid. (Zeitschrift des Österreichischen Ingenieurs Architekten Vereins, 1946, vol. 91, Nov. 26, pp. 181–187).

The Cupola Furnace. J. T. Mackenzie. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 1–16). Developments in modern cupola design and practice that have taken place since John Wilkinson's patent of 1794, are discussed.—R. F. F.

Variables Affecting Carbon Control in Cupola Operation. W. W. Levi. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 626–632). *See* Journ. I. and S.I., 1948, vol. 158, Feb., p. 267.

Thermochemical Analysis of Combustion in a Cupola. H. E. Flanders. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 533–545). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 142.

Cupola Melting Phenomena. E. V. Somers and D. W. Gunther. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 441–450). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 142.

Anthracite Coal Conserves Coke. F. J. Fredriksen and E. Bremer. (Foundry, 1948, vol. 76, Sept., pp. 84–85, 164, 166). Brief details are given of the cupola practice developed by the Westinghouse Electric Corp. to deal with the short supply and poor quality of coke by replacing some of it with anthracite.—R. A. R.

Melting Rate of Cupola Furnaces. F. D. Homen de Melo. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Apr., pp. 173–176 : [Abstract] Metals Review, 1948, vol. 21, Aug., p. 4). A formula is given for the calculation of the melting rate based on various operating factors. Data obtained agree quite satisfactorily with those of experimental investigation.

Operation and Control of the Cupola. W. W. Levi. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 808–817). The author describes cupola practice at the plant of the Lynchburg Foundry Co., Lynchburg, Pa., where sand-cast high-pressure pipe and fittings, engine cylinder jackets, liners, and other castings are produced. Three types of coke (by-product, beehive, and pitch) are used, and the effect of each type on carbon pick-up is shown. The control of the cupola mixtures is dealt with.—R. E.

Hot Blast Cupola Furnaces. M. Novinsky. (Boletim da Associação Brasileira de Metais, 1948, vol. 4, Apr., pp. 164–172 : [Abstract] Metals Review, 1948, vol. 21, Aug., p. 38). The recuperation of heat in cupola furnaces is studied from the point of view of coke conservation. The suitability of different types of cupola furnaces for use in Brazil is discussed.

Economics of Cupola Operational Control. F. K. Vial. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 507–541). Numerous tables and charts are presented showing the development and distribution of heat in cupolas, for both hot- and cold-blast practice.—R. E.

Lining and Patching of Cupola Refractories. E. J. Lally. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 749–751). The importance of the proper methods and selection of materials for the lining and patching of cupolas is pointed out.—R. E.

Malleable Iron Finishing. E. M. Strick. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 510–515). Rules are suggested for fettling and grinding malleable iron castings, in particular for dealing with them before the annealing treatment.—R. A. R.

Material Handling in a Malleable Foundry Processing Department. N. J. Henke. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 476–481). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 143.

Mechanized Malleable Foundry Finishing and Inspection. D. F. Sawtelle. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 388–391). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 143.

Malleable Foundry Finishing and Inspection. T. E. Poulson. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 451–460). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 143.

Malleable Foundry Control. C. F. Joseph, (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 818–823). The control of melting and moulding operations for the production of malleable iron castings is discussed.

Preparation of Foundry Sands for Market. F. P. Goettman. Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 490–492). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 144.

Chemically Treated Sand—A Molding Sand Process with a Resin Bond. T. W. Curry. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 39–52). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 469.

New Tentative Standards for Grading and Fineness of Sands. R. E. Morey. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 381–387). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 144.

Seventh Annual Report of Investigation of Properties of Steel Sands at Elevated Temperatures. D. C. Williams and P. E. Kyle. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 606–619). The furnace, specially designed to carry out these researches, is described. Tests were carried out to study the reproducibility of the results of hot compressive tests, also to determine the time required to heat test specimens to a constant temperature and the hot compressive strengths of moulding sand mixtures over a wide range of temperature, including all maximum temperatures to which sand is subjected in a mould during casting. Results obtained are shown in graphs and tables.
R. F. F.

Thermal Conductivities of Three Sands. C. F. Lucks, O. F. Linebrink and K. L. Johnson. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 62–65). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 144.

Density of Molding Sand. H. W. Dietert, H. H. Fairfield, and E. J. Hasty. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 175–190). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 144.

A Study of the Precision of Sand Test Data. R. E. Morey and C. G. Ackerlind. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 288–295). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 144.

Physical Properties of Molding Sands. G. R. Gardner. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 332–336). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 144.

A.F.A. Clay and Fineness Determinations Can Be Quantitative. D. C. Williams. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 727–731). A procedure is described for selecting the proper electrolyte to use with tap water for the A.F.A. test for the determination of the clay content of foundry sands. A satisfactory electrolyte consists of 25 ml. of 1% potassium oxalate and 475 ml. of tap water.—R. E.

Behavior of Molding Materials in "Own Atmosphere" at Elevated Temperatures. H. W. Dietert and R. L. Doelman. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 610–615). In a mould the gases generated by the various ingredients of the mould surface layer are held within the mould cavity, along the metal-mould interface and also in the backing sand ; thus the sand is surrounded by its own gases, a condition which the authors have termed "own atmosphere." An investigation on the effect of these gases on the behaviour of moulding materials at high temperatures is described. It was found that the hot strength of a moulding sand with an addition of 2% of a cereal binder was lower in own atmosphere than in an oxidizing atmosphere. With 20% of silica flour the hot strength was also lower, while with an addition of silica flour and cereal binder in combination it was higher in own atmosphere than in an oxidizing atmosphere. Sea coal in moulding sand caused the hot strength to be materially higher in own atmosphere. With an addition of pitch the hot strength of moulding sand was higher at 2500° F. in own atmosphere, but lower at 2000° F. The hot strength of core sand bonded with combustible binders, such as oil, was increased by own atmosphere and reduced by oxidizing atmosphere. The addition of pitch to a core mixture caused the hot strength at 2500° F. to be much higher in own atmosphere than in oxidizing atmosphere.—R. E.

Molding Sand Binders. L. Jenicek. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 845–860). The author discusses bond properties and strength, the forces active in the green state between sand and clay and between sand and organic binders, and the viscosity of binders and its influence on green compressive strength. The viscous properties of binders are discussed with special emphasis on thixotropy which is defined as the proportion of the volumes of liquid and solid matter which is required, one minute after shaking, for the suspension just to flow out of

an 8-mm. dia. test tube, when the test tube is changed from a vertical to a horizontal position.—R. E.

Malleable Foundry Coremaking Practice. D. F. Sawtelle. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 691–695). Practice at the plant of the Malleable Iron Fittings Co., Bramford, Conn., for the production of cores is described and illustrated.—R. E.

Principles of Precision Investment Casting. K. Geist and R. H. Kerr, jun. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 17–33). *See* Journ. I. and S. I., 1947, vol. 157, Dec., p. 636.

Centrifugal Casting. J. E. Hurst. (Iron and Steel, 1948, vol. 21, Aug., pp. 355–361). A general review is presented of the present state of knowledge of centrifugal casting, with accounts of the different processes and references to the work of various investigators.—J. C. R.

Freezing Rate of White Cast Iron in Dry Sand Molds. H. A. Schwartz. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 66–74). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 294.

Studies on Solidification of Castings.—Approximate Equation for Steel Castings. V. Paschkis. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 74–76). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 294.

Cloth Type Dust Collectors. G. A. Boesger. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 745–748). The author discusses the design of tube or bag-type and the screen-type of dust collectors.—R. E.

Fans and Exhausters. P. Cohen. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 720–723). The author discusses centrifugal fans, squirrel-cage type fans, radial-blade or paddle-wheel type fans and non-overloading fans for the collection of dust, especially in foundries—R. E.

Bore Cracks in Cast Steel Fittings and Valve Bodies. H. F. Taylor, H. F. Bishop, and W. H. Johnson. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 670–690). Bore cracks are hot tears which occur in the bores of valves and fittings under the flanges. They are caused by stresses resulting from contraction of the casting and occur after the barrel of the casting has solidified, at which time the stresses which prevent linear contraction exceed the strength of the metal skin beneath the flange. The defect can be eliminated by: (1) The use of a hollow core, which can be deformed by the circumferential contraction of the casting, automatically relieving the stresses and permitting linear contraction to take place, and (2) the use of graphite collars or properly designed steel chills in the core which strengthen the metal in the casting so that its strength exceeds the imposed stress. Theories of the cause and formation of veins, which are closely allied to bore cracks are also presented.—R. E.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Heat Treatment of Cast Iron. W. L. Allen. (Proceedings of the Australian Institute of Foundrymen, 1942–1943, vol. 3, pp. 265–279). The annealing and hardening of cast iron, the properties of cast iron in the quenched and tempered state, and the flame-hardening of cast iron are described and discussed.—R. A. R.

Homogenization Heat Treatments for Cast Steel. J. G. Kura and P. C. Rosenthal. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 154–183). *See* Journ. I. and S.I., 1947, vol. 156, July, p. 442.

The Heat-Treatment of Chains. M. G. van der Steeg. (Iron and Steel Institute, 1948, Translation Series, No. 354). This is an English translation of a paper which appeared in Metalen, 1947, vol. 1, June, pp. 190–192; July, pp. 207–209. R. A. R.

American Heat Treatment Practice for Steel Strip in the Controlled Atmosphere Vertical Electric Furnace. (Revue de Chauffage Électrique, 1947, vol. 15, Jan.–Feb., pp. 3–4: [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Feb., p. 21). A description is given of a furnace for the bright-annealing of copper alloys and steel strip less than 1·8 mm. thick. Up to seven 18-cm. widths of strip can be annealed side by side.

Salt Baths for Metals. E. L. Cady. (Scientific American, 1947, vol. 176, Apr., pp. 164–166).

Temper Hardening of Carbon Steel. K. F. Starodoubov. (Comptes Rendus de l'Académie des Sciences, U.R.S.S., 1946, vol. 53, No. 3, pp. 213–215).

Ferrotherm Plant Specializes in Bright Hardening, Annealing, and Brazing. (Industrial Heating, 1948, vol. 15, Mar., pp. 492–494, 496, 498; Apr., pp. 675–682). The construction and operation of electrically heated furnace with controlled atmospheres for brazing and bright-annealing steel are described.—M. A. V.

Gas Carburising with Town's Gas. D. S. Laidler. (Metallurgia, 1948, vol. 38, May, pp. 46–49). The Wild-Barfield gas-carburizing unit includes a catalyser which removes CO_2 and oxygen, and air coolers to remove moisture.—J. P. S.

Gas Carburizing Equipment. (Engineer, 1948, vol. 185, June 4, p. 551). Raw town gas is unsuitable for gas-carburizing owing to the cracking of hydrocarbons. An equipment has been developed by Wild-Barfield Electric Furnaces, Ltd., in which the gas is passed over a catalyst. This removes most of the unsaturated hydrocarbons and increases the carbon monoxide content, and leaves the gas suitable for gas-carburizing, as the only carbon deposited on the steel will be powdered graphite, which is not harmful.—M. A. V.

Gas Cyaniding Small Parts. H. N. Ipsen. (Iron Age, 1948, vol. 161, May 27, pp. 84–87). A description is given of new equipment for gas-cyaniding small parts at the rate of about 135 lb. of steel per hr. A case 0·010 to 0·012 in. deep can be obtained by 30 min. treatment at 1550° F. Details of the cost of the process are given.—R. A. R.

The Practical Use of a Controlled Atmosphere. A. W. Frank. (Industrial Heating, 1948, vol. 15, July, pp. 1124–1130). Recommendations are made on the operation of generators for producing protective atmospheres and of small heat-treatment furnaces for tools.—R. A. R.

Residual Stresses in Case-Hardened Steel Specimens, Quenched from Temperatures below Ac_3. E. S. Yakovleva and M. V. Yakutovich. (Journal of Technical Physics U.S.S.R., 1948, vol. 18, Feb., pp. 207–210 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, Aug., p. 38). Residual stresses were determined experimentally for 0·12% carbon steel, case-hardened to a depth of 0·7 to 0·8 mm, and quenched from 810° C. in water.

The Practical Economics of Radio Frequency Heating. B. T. P. Kinn. (Iron Age, 1948, vol. 161, June 10, pp. 72–79). Charts are given for determining the size of radio-frequency generator required for a given operation such as through-heating, joining similar or dissimilar metals by brazing or soldering, surface hardening, and dielectric heating. Other factors taken into account are the cost of operation of the generator on various work cycles, and the handling costs. J. P. S.

New Universal Inductor for High Frequency Hardening of Steel. V. V. Alexandrov and S. M. Gamazkov. (Vestnik Machinostroenia, 1948, No. 2, pp. 43–46: [Abstract] Engineers' Digest (London), 1948, vol. 9, Sept., p. 304). A new universal inductor, which consists of a main structure and interchangeable inserts, which is capable of case-hardening a wide range of shape or size, is described.—R. F. F.

Proper Frequency for Induction Heating of Nonmagnetic Metals. J. T. Vaughan and H. B. Osborn, jun. (Metal Progress, 1948, vol 54, July, pp. 46–50). The author discusses the selection of frequency for the induction heating of non-magnetic materials such as copper, aluminium, and austenitic steels. He considers heating efficiency, inductor input, and heat pattern.—R. E.

Fixtures Facilitate Induction and Flame Hardening. V. E. Hillman. (Iron Age, 1948, vol. 161, June 24, pp. 90–94). Examples of ingenious heating coils, quenching devices, and other fittings for induction heating and flame-hardening are described and illustrated.—R. A. R.

High Frequency Electric Heating. Essential Results of Recent Theories and Directions for the Design of Furnace Elements. M. Jouguet. (Mémoires de la Société des Ingénieurs Civils de France, 1947, vol. 100, May–June, pp. 283–307).

History of High-Frequency Heating. M. Fourment. (Mémoires de la Société des Ingénieurs Civils de France, 1947, vol. 100, May–June, pp. 267–282). The author surveys the origin and development of high-frequency heating under the headings of high-frequency melting, high-frequency heat-treatments, and dielectric heating.—J. C. R.

The Annealing of Gears by High-Frequency Induction Heating. M. I. Shitov. (Stanki i Instrument, U.S.S.R.,

1947, vol. 18, Sept., pp. 13–16 : [Abstract] Index Aeronauticus, 1948, vol 4, May, p. 49). Experience over a number of years in the high-frequency annealing of machine tool gears indicates the desirability of normalizing before high-frequency treatment. The favourable current density is 1·8–2 kW./29 sq. cm. surface, using a high-frequency valve generator of suitable output. Depth of annealing should be not less than 2 mm. For gears exposed to impact loads, annealing after case-hardening or high-frequency surface annealing is suggested.

High Frequency Heating. H. P. Debruyn. (Bulletin de la Société Belge des Électriciens, 1948, vol. 64, Jan.–Mar., pp. 1–18 : [Abstract] Bulletin of the British Scientific Instrument Research Association, 1948, vol. 3, Aug., p. 231). A general account of the theory of high-frequency induction and dielectric heating is given. Industrial applications touched upon include welding and surface heating of metals, wood drying, and thermal treatment of plastics.

Metallographic Control of Tools of EI-262 Steel After Heat Treatment. V. S. Sagaradze and D. I. Kniajitskaia. (Zavodskaya Laboratoriya, 1946, vol. 12, No. 7–8, pp. 700–702).

Nitriding. H. Wiegand. (Revue de Métallurgie, Mémoires, 1948, vol. 45, Mar.–Apr., pp. 105–117). In the first part of the paper the author discusses the purpose of nitriding, the process, nitriding steels, the properties of the nitrided layer and its influence on the interior of the steel, the behaviour of nitrided steels under wear, corrosion, tension, shock, and fatigue, fatigue resistance for a limited period and the possibility of overloading nitrided layers, roughness of the layers, their tendency to fissuring, and partial nitriding. In the second part the influence of nitriding on various machine parts—screws, nuts, crankshafts, connecting rods, cylinders, valves, gear wheels, etc.—is discussed.—A. E. C.

Steel Castings and Weldments Residual Stress Relief. C. R. Jelm and S. A. Herres. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 241–251). *See* Journ. I. and S. I., 1947, vol. 155, Jan., p. 151.

Stress Relieving Large Gray Iron Castings for Diesel Engines. K. G. Presser. (Industrial Heating, 1948, vol. 15, June, pp. 932–938). An illustrated description is given of a large car-bottom furnace for stress-relieving cast-iron Diesel-engine cylinder blocks ; it is heated by circulating the products of the combustion of fuel oil. The treatment consists of heating to 900° F. at 120°/hr., holding for 1 hr. or more, depending on the section thickness, and cooling at 40°/hr.

Graphitization of White Cast Iron—Effect of Section Size and Annealing Temperature. R. Schneidewind, D. J. Reese, and A. Tang. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 252–259). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 143.

FORGING, STAMPING, DRAWING, AND PRESSING

Exhaust Steam for Forge Presses. A. A. Nikolayev and A. M. Dalin. (Za Ekonomiya Topliva, 1947, No. 10, pp. 23–27).

Nature of the " Forging Cross " in Steel. V. I. Arkharov, N. V. V'yal and K. A. Malyshev. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Feb., pp. 219–223 [in Russian] : [Abstract] Metals Review, 1948, vol. 21, Aug., p. 42). The phenomenon consists of a clearly visible cross-shaped design which appears on the etched surface of specimens which were rotated during forging, between blows of the hammer, to positions at right angles to each other. Attempts are made to explain this phenomenon on the basis of a particular distribution of coarse and fine grains which is thus produced.

Cold Extrusion of Steel. (Enamelist, 1947, Nov., pp. 28–31).

Steel Shapes Formed by Cold Extrusion. K. Rose. (Materials and Methods, 1948, vol. 27, May, pp. 68–71). Cold extrusion is a multi-step process resembling impact extrusion. Examination of German work during the war indicates the following features : (1) The material is phosphatized before treatment ; (2) the process commences with a cupping operation ; (3) close tolerances, and usually the final form, may be obtained ; and (4) standard presses can be used. It is suggested that with superior American die steels, the process may be developed into a competitor with other methods of fabrication. J. P. S.

The Theory of " Unit Compressive Stress " of Metals during Drawing. S. I. Gubkin. (Bulletin de l'Académie des Sciences (U.R.S.S.), Classe des Sciences Techniques, 1947, Dec., pp. 1663–1681 [in Russian] : [Abstract] Metals Review, 1948, vol. 21, May, p. 38). According to the theory proposed. the energy involved in wire-drawing operations may be divided into that used for " basic " deformation, " additional " deformation, and that required to overcome frictional forces. Formulæ for the calculation of these values are given.

Metallurgy of " Ampco 24 " Aids Forming and Drawing of Stainless Steel. J. C. Kemp. (Tool and Die Journal, 1948, vol. 14, July, pp. 68, 70, and 116 : [Abstract] Metals Review, 1948, vol. 21, Aug., p. 40). " Ampco 24 " is a new bronze alloy for dies which possesses unusual wear resistance because of a new intermetallic compound. Ten companies tried out the alloy on the production line and reported service lives two to five times those of bronze dies.

Experimental Investigation of the Specific Pressure of Metal Flow during Drawing. S. J. Gubkin. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Techniques, 1948, Feb., pp. 239–250 [in Russian] : [Abstract] Metals Review, 1948, vol. 21, Aug., p. 42). Results are given for both ferrous and non-ferrous metals using a specially developed apparatus. Experimental data agreed closely with results of theoretical calculations, using a newly derived formula.

Calculating the Power Requirements for Drawing with Back Pull. W. Lueg and J. Haas. (Mitteilung aus dem Kaiser-Wilhelm-Institut für Eisenforschung : Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 137–143). A modification of F. Körber and A. Eichinger's formula for calculating power requirements for wire-drawing with back pull is presented ; it makes greater provision for the reduction in the work of displacement when considerable back pull is applied.

Diagrams are also given for rapidly determining the optimum die angle for obtaining reductions of 5% to 50%, using back pull, under different conditions of friction.

It is shown that the preliminary deformation and the increase in strength resulting from it can be determined from the stress-deformation diagram for the undeformed material. R. A. R.

The Design of Drawing Dies for Wire Drawing Having Regard to Drawing Work and Conditions of Friction. E. Siebel, N. Ludwig, and P. Melchior. (Werkstatt und Betrieb, 1948, vol. 81, July, pp. 177–180). Formulæ are developed for calculating the optimum shape of wire-drawing dies, and a proposal for standardizing the design of hard-metal dies is made.—R. A. R.

Temperature Distribution in Wires during Wire-Drawing. H. Korst. (Öst. Ing. -Arch., 1948, vol. 2, No. 2, pp. 132–137 : Electrical Engineering Abstracts, 1948, vol. 51, Aug., p. 219). During wire-drawing, wires are heated by the friction in the die and by the work done due to change of dimensions. To prevent overheating it is necessary to calculate the wire temperatures. Previous simplified formulæ assumed a parabolic temperature distribution. The paper gives the exact solution of the partial differential equation representing the temperature distribution. The exact method and the simplified parabolic theory give approximately the same values for the temperature distribution near the wire surface. Inside the wire, however, they differ appreciably.

Control of Drives in Modern Wire Manufacture. C. C. Downie. (Power Transmission, 1946, vol. 16, Dec. 15, pp. 1261–1263).

MACHINERY FOR IRON AND STEEL PLANT

Modern Boiler Design Increases Availability. A. R. Mumford. (Combustion, 1948, vol. 19, Feb., pp. 35–41 : [Abstract] British Coal Utilisation Research Association, Monthly Bulletin, vol. 12, Apr., p. 143). Steam-generating units for use in the American steel industry are usually designed for separate or simultaneous burning of two to four different fuels. The author discusses means for the control of slag formation on heating surfaces, including cooling screens, adjustable-position burners, and variation in the relation of flame envelope to water-cooled furnace area. Six recent units with capacities between 75,000 and 325,000 lb./hr. are briefly described.

Handling of Sheet Steel. R. L. Franing. (Finish, 1948,

vol. 5, No. 3, pp. 21, 64 : American Ceramic Abstracts, vol. 31, Aug. 1, p. 172). Efficient handling of materials requires the proper selection and use of equipment to the best possible advantage dependent upon the volume of production, the type of product to be handled, the expenditure of energy required, and the costs involved. In the East Moline Works of the International Harvester Co. the different types of handling equipment are integrated in the flow of raw material, from receipt to shipment of the end products from the factory.

In the Open Hearth Area. H. G. Tregillus. (Blast Furnace and Steel Plant, 1948, vol. 36, Aug., pp. 954–956). It is suggested that structures for open-hearth crane runways should be constructed as continuous girders, a design which will reduce the amount of steel required and avoid the concentration of stress which may occur in conventional structures.—J. P. S.

Dynamic Capacity of Rolling Bearings. (Ball Bearing Journal, 1947, No. 3–4, pp. 50–61). The calculation of the dynamic capacity of rolling bearings has hitherto been based on empirical formulæ which have been used with considerable success for conventional types of bearings. In this paper a unitary statistical theory is established for the dynamic capacity of rolling bearings, allowing for the variation in the resistance of the material from one element of volume to another. Hertz's theory for the " contact of elastic solids " is developed for the calculation of the tension variation which can be assumed to be most dangerous if the bodies roll on each other. Although the theory cannot take into consideration all the factors affecting the bearing life, it agrees satisfactorily with practical experiments.

Rolling Bearing Applications. R. K. Allan. (Journal of the Institution of Production Engineers, 1948, vol. 27, Aug., pp. 401–432). This comprehensive account of rolling bearing applications covers the characteristics of rolling bearings, bearing life, limits of accuracy, gauging bearing seatings, mounting faults, bearing failures, lubrication, and applications in many types of machine.—R. A. R.

WELDING AND FLAME-CUTTING

Testing Electrodes—Weld Metal Specimens. H. H. Marsh. (New Zealand Institute of Welding : New Zealand Engineering, 1948, vol. 3, June 10, pp. 586–591). The manner in which welding procedure and the dimensions and preparation of weld-metal specimens affect the results of tests on welding electrodes is discussed.—R. A. R.

A New High Strength Welding Rod. L. Tarnopol. (Welding Journal, 1948, vol. 27, July, pp. 517–521). The experimental welding rod ' Planeweld AWF 144–4130 ' has been tested by the Douglas Aircraft Co. in the welding of landing-gear assemblies. Welds in 1-in. thick sections are generally satisfactory, though the high manganese (2%) and chromium (1·8–2%) in the deposited metal tends to produce temper brittleness and the high manganese may lead to cracking if the parts are quenched too severely after heat-treatment. The composition of the deposited metal varies considerably with welding procedure and current and close control is required.—J. P. S.

Welding of Basic and Acid Bessemer Steel. G. P. Michajlov. (Avtogennoe Delo, 1947, No. 10, pp. 9–11 : [Abstract] Svarovani, 1948, No. 5). Experiments have shown the non-uniform distribution of sulphur, phosphorus, nitrogen, and oxygen in acid and basic Bessemer steel. A surface layer about 1·5–2·5 mm. deep contains considerably lower percentages of these than the deeper layers. In several samples cut from various parts of a basic Bessemer steel joist the phosphorus varied between 0·020% and 0·073%, sulphur between 0·016% and 0·049%, and nitrogen between 0·013% and 0·023%. Notch-impact test data (Mesnager and Charpy) for specimens cut from an acid Bessemer joist are presented and show decreasing values as the testing temperature was successively lowered from ± 20° to − 20° and − 50° C. Different fatigue strengths were also noted for specimens cut from different depths of an acid Bessemer joist. Blue-brittleness tests were also made at temperatures of 275°, 350°, and 425° C. The results of these tests showed that cracks in welds are due to harmful elements migrating from the base metal to the weld metal, whilst cracks in the parent metal are due particularly to blue brittleness. It is suggested that the guiding principle should be to make the weld in several layers to prevent contamination of the weld metal. The successive layers have progressively smaller contents of harmful constituents. The electrode coatings should contain considerable amounts of manganese and titanium which counteract the harmful effects of sulphur, nitrogen, and oxygen. It is advisable to weld in several layers using small-diameter electrodes to prevent cracks in the parent metal, particularly those due to blue brittleness.—R. A.

Automatic Welding with Carbon Electrodes and Fluxing Powder. N. A. Olshanskyj. (Avtogennoe Delo, 1948, No. 3, pp. 16–18 : [Abstract] Svarovani, 1948, No. 5). A method of automatic welding with carbon electrodes has been developed and the welding process takes place under a layer of flux in powder form. The arc does not blow the powder about. It is stable with A.C. even if the current values are low, and it is thus possible to weld thin sheets. Welding speed is three to five times higher than the speed obtained with standard methods. The electrode holder is of special design giving control of the length of the arc, and the clamping device is suitable for butt, lap, and seam welding. The current is supplied by welding transformers or by D.C. welding sets. Consumption of electrode material with A.C. is about twice as high as with D.C. with correct polarity, and if the D.C. polarity is reversed the electrode consumption is increased to five times the normal value. Fluorspar, ferrosilicon, and ferromanganese are added to the flux and special fluxes in powder form are provided for non-ferrous metals. Welding experiments were carried out for low-carbon sheets 2 mm thick without using filler rods, and the current consumption was determined for butt, lap, and seam welding for various welding speeds. E. G.

Submerged or Hidden-Arc Welding. L. A. Woodworth. (South African Welder, 1948, vol. 1, July, pp. 3–7). Experience gained on first using a hidden-arc welding machine is reported. Some trouble with blowholes occurred, which was found to be due to moisture ; it was cured by baking the coating material and the wire and warming the work before welding commenced.—R. A. R.

The Fatigue Strength of Welds as the Basis for Calculations Relating to Welded Bridges. Folkhard. (Schweisstechnik, 1948, vol. 2, Aug., pp. 93–103).

Research on Arc-Welded Butt Joints of Mild Steel. G. Welter. (Welding Journal, 1948, vol. 27, July, pp. 321-s–369-s). An investigation has been carried out on arc-welded butt joints in mild steel, the ductility, impact-tensile resistance, the effect of notching, of cylic loads and of axial or eccentric loads being studied, both at room and sub-zero temperatures. No failures occurred in the weld material, even in material of low ductility. The author therefore ascribes known failures of welded structures such as ships and bridges to other factors, on which small specimens and model structures do not give enough information. It is not certain that this applies to higher alloy welds.—J. P. S.

State of Stress in Arc Welds Made under Transverse Restraint. E. F. Nippes and W. F. Savage. (Welding Journal, 1948, vol. 27, July, pp. 370-s–376-s). Welds were made between plates restrained to the ' cracking limit,' *i.e.*, the maximum degree of restraint possible before cracking appeared as the first-pass weld metal. Restraint was imposed by welding the free edges of the plate to a fixture. It was found that the transverse stresses approached 65,000 lb./sq. in., the ultimate strength of the deposited metal when a backing strip was employed, and that, without a backing strip, the threshold of cracking corresponded to 80% of the ultimate strength of the deposited metal. The shape of the cross-section of the weld deposit affected the cracking tendency which was greatest with concave deposits and least with convex.

In complete welds made with the first pass at the ' cracking limit ' there was no useful relationship to be found between first-pass cracking limit stresses and the transverse stresses in the completed welds.—J. P. S.

Standards for Welds in Ship Construction. R. J. W. Rudkin. (Institute of Physics, Industrial Radiology Group, Symposium : Welding, 1948, vol. 16, Aug., pp. 335–338). The scope of radiographic inspection for ships' welds is discussed and recommendations on standards of acceptance are made. R. A. R.

Radiological Standards for Pipe Welds. W. J. Wiltshire. (Institute of Physics, Industrial Radiology Group, Symposium : Welding, 1948, vol. 16, Aug., pp. 339–345). The

difficulties encountered in making radiographic examinations of welds in pressure pipes are explained and satisfactory techniques are described. It is emphasized that the standards for pipe welds should not be lower than for pressure welds. R. A. R.

Threadless Pipe Fittings. (Railway Age, 1948, vol. 124, Apr., 10, pp. 56–57 : Railway Engineering Abstracts, 1948, vol. 3, Sept., p. 235). Threadless malleable fittings for brazed pipe joints are now being made in the United States. The use of these fittings enables steel or wrought iron pipe without thread, to be joined by brazing. The fitting consists of a black malleable-iron socket, and the method of forming the joint is described in detail and illustrated. The use of silver brazing alloys is recommended for joints in pipework of industrial installations where pressures of 300 lb./sq. in. and temperatures up to 400° F. are contemplated. The joint is known as the Flagg-Flow joint and its use for steam and fuel piping, water supplies, boiler feed pipes, air and radiant heat piping, gas, etc., is suggested. The use of this threadless fitting is claimed to simplify pipe-work layouts.

Power Plant Pipe Welds. J. F. Magee. (Institute of Physics, Industrial Radiology Group, Symposium : Welding, 1948, vol. 16, Aug., pp. 330–334). Radiographic examination on site of welds in pipelines for steam turbines is discussed and recommendations for acceptance standards are made.—R. A. R.

Stainless Steel Sheet Welding. N. E. Parks. (South African Welder, 1948, vol. 1, Jan., p. 19). Oxy-acetylene, atomic-hydrogen, and electrical resistance welding procedures for stainless steel sheet are very briefly described.—R. A. R.

Large Stainless Steel Filters. (Instruments, 1947, vol. 20, Dec., pp. 1134–1135). An account is given of a new welding technique enabling large filters to be made in stainless steel.

Fabrication of High-Nickel Alloys and Austenitic Stainless Steel. A. S. Tuttle, jun. (Pulp and Paper Magazine, 1948, vol. 49, No. 5, pp. 74–80).

Welds in Armour—The Search for Standards. O. E. Chapman and R. W. Angle. (Institute of Physics, Industrial Radiology Group, Symposium : Welding, 1948, vol. 16, Aug., pp. 345–349). The special difficulties associated with the radiographic examination of welds, particularly **T**-joints, in armoured fighting vehicles are described. Visual, supersonic, and magnetic testing are briefly reviewed.—R. A. R.

Rail-End Welding. (South African Welder, 1948, vol. 1, Jan., pp. 5–8). Damage or ' batter ' at rail ends is described and details are given of the welding technique adopted by the South African railways to build up worn rail ends.—R. A. R.

Maintenance Welding in a Steel Plant. F. J. Gaydos. (Welding Journal, 1948, vol. 27, July, pp. 527–530). At the Gary Works of the Carnegie Illinois Steel Corporation self-propelled units, carrying a 300 amp. welding generator, as well as oxy-acetylene gear, are used in emergency repairs ; where higher amperages are required, such machines are only employed while the conventional motor-generator set is being brought up. The work done includes hard-facing of journals, wobblers, and roll-guides and general fabrication. J. P. S.

Techniques of Quality Welding of Plain Carbon Steel Castings. E. LaGrelius and J. D. Wozny. (American Foundrymen's Association, 1948, Preprint No. 48-8). The authors describe an investigation carried out to find electrodes which would give welds possessing a satisfacory degree of soundness which would also deposit weld metal possessing certain minimum physical properties. A number were investigated and it was found that organic coated electrodes are not suitable for the repair welding of plain carbon steel castings owing to their tendency to produce pinhole porosity. Lime or mineral-coated electrodes generally produced welds free from pinhole porosity.—R. E.

Arc Welding of Cast Iron with Nickel Electrodes. T. E. Kihlgren and L. C. Minard. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 357–367). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 148.

Diseases Occurring from Welding Armour Plate with Low Alloy Electrodes. J. Růžek, M. J. Kotěra, and V. Krahulík. (Strojnický Obzor, 1947, vol. 27, Mar., pp. 139–142). [In Czech]. During the war countries under German domination were compelled to use low-alloy electrodes with various coatings for welding armour plates. A basic coating permits considerable saving of chromium and manganese. While welding with these electrodes large quantities of fluorine were involved and several welders became ill. At first chromium poisoning was suspected, but investigations showed that that was not the cause, and also that the paint was free from harmful admixtures. To find out how much fluorine is driven off during welding two German electrodes (RND and PNA) were melted down on armour plate and the solidified weld metal and one each of the unused electrodes were analysed. It was found that 0·15 g. of fluorine is evolved from each electrode, *i.e.*, a total of 83 g./8-hr. shift. Welders working inside armoured vehicles thus underwent grave risks. Protection with respirators was found impracticable. Use of an alkali paste was found satisfactory and this was applied to the mucous membrane every 4 hr. In addition the welders were required to consume extra milk, and the ventilation was improved.—E. G.

Need for Supplementary Treatment on Pieces of Oxy-Acetylene-Cut Steel. G. Ancion. (Revue de la Soudure, 1945, vol. 1, pp. 27–38 : British Abstracts BI, 1948, July, col. 328). Previous work on this subject is reviewed and it is shown that, after oxy-cutting, only a brushing is needed for steel with a tensile strength of $\geq$ 55 kg./sq. mm. provided that the edge is smooth enough for welding ; for steels of greater strength, post- or preheating of the cut pieces to 250–400° is needed.

POWDER METALLURGY

The Structure of Hard-Metal Alloys. H. Franssen. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 79–84). The microstructures of the following alloys prepared by powder metallurgy are discussed : (*a*) Tungsten-carbon, (*b*) tungsten-carbide/cobalt, and (*c*) tungsten-carbide/titanium-carbide/cobalt.—R. A. R.

Non-Uniform Changes in the Shape of Metal-Powder Compacts during Sintering. H. Franssen. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 91–92). The unequal shrinkage of compacts during sintering is caused by the non-uniform distribution of the ingredients during pressing, differences in temperature across the section while heating, and the influence of specific gravity.—R. A. R.

Powder-Metallurgy Parts from Iron and Carbon. H. Wiemer and W. A. Fischer. (Kaiser-Wilhelm-Institut für Eisenforschung : Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 125–135). Laboratory tests were made on bars, produced by powder metallurgy from mixtures of iron powder and carbon, to determine the effects on the physical and mechanical properties of sintering, tempering, and time, the atmosphere, and the nature and origin of the two ingredients. Powder metallurgy can be used to produce parts with ferritic-graphitic, ferritic-graphitic-pearlitic, or pearlitic structure. The strengths obtained vary from 1–2 kg. to 50–60 kg./sq. mm. according to the sintering time and temperature, and the amount and nature of the carbon ; the sintering atmosphere has little effect. Curves are presented to show how the carbon content in the 0·3–1·0% range affects the strength, hardness, and elongation of compacts made at pressures in the 6–8 tons/sq.cm. range, and sintered at 1200–1300° C. for periods of 2 to 8 hr. By heat-treatment it was possible to produce compacts with a tensile strength exceeding 100 kg./sq.mm., but they were very brittle. On the basis of equal tensile strength, heat-treatment did not improve the other mechanical properties.—R. A. R.

The Sintering of Electrolytic Iron Powders. (Pratique des Industries Mécaniques, 1948, vol. 31, Jan., p. 21 : [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Apr., p. 43). Problems arising out of sintering processes are discussed. The conditions and results of tests are noted with reference to the importance and rapidity of diffusion, the influence of the number and the surface contacts between particles, and the rate of plastic deformation of the mass. Hot pressing gives better results than cold pressing.

PROPERTIES AND TESTS

Physical Tests. T. Child. (British Engineering Export Journal, 1948, vol. 31, July, pp. 110–112). Brief descriptions are given of hardness, tensile, fatigue, and balance testing machines which can be installed in production lines for the rapid testing of parts produced in large quantities.—R. A. R.

Size Effects in Steels and Other Metals. P. E. Shearin, A. E. Ruark, and R. M. Trimble. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947,

pp. 158–162). Investigations of the effect of specimen size on the mechanical properties of metals are briefly reviewed and some results of the authors' slow-bend tests on 2·5-in. plate of nickel–chromium steel are reported. In the range of heat-treatments and specimen dimensions covered, the size effect for this steel is quite insensitive to grain-size and microstructure.—R. A. R.

Influence of the Composition and the Structure of Metals on Their Mechanical Properties. A. A. Bochvar. (Bulletin de l'Académie des Sciences (U.R.S.S.), Classe des Sciences Techniques, 1946, No. 5, pp. 743–752).

The Use of Flat-Ended Projectiles for Determining Dynamic Yield Stress. I—Theoretical Considerations. Sir Geoffrey Taylor. (Proceedings of the Royal Society, Series A, 1948, vol. 194, Sept. 2, pp. 289–299). It has long been known that metals may be subjected momentarily to stresses far exceeding their static yield stress without suffering plastic strain. One of the simplest methods for subjecting a metal to a high stress for a short time is to form it into a cylindrical specimen and fire this at a steel target. The front part of this projectile crumples up, but the rear part is left undeformed. If the target is rigid the distance which this portion travels while it is being brought to rest may be taken as the difference between the initial length and the length of the deformed specimen after impact. Knowing the velocity of impact, a minimum possible value can be assigned to the maximum acceleration of the material, and from this a minimum value for the yield stress can be calculated. The actual yield stress is considerably greater than this minimum, and methods are given for calculating a more probable value.

The Use of Flat-Ended Projectiles for Determining Dynamic Yield Stress. II—Tests on Various Metallic Materials. A. C. Whiffin. (Proceedings of the Royal Society, Series A, 1948, vol. 194, Sept. 2, pp. 300–322). The experimental technique devised to apply the technique outlined in Part I (*see* preceding abstract) is described and the results obtained with various steels, duralumin, copper, lead, iron, and silver are presented. The rates of strain in the tests were of the order of 10^4 in./in./sec. The method was inaccurate at high and low velocities. Within the range of weapons available there was little change in dynamic strength with alteration of the specimen dimensions. In general, the dynamic compressive yield strength S was greater than the static strength Y represented by the compressive stress giving 0·2% permanent strain. For steels of various types, regardless of composition and heat-treatment, there was a relation ($S/Y = 5{\cdot}98 - 2{\cdot}42 \log_{10} Y$) between the ratio S/Y and the static strength Y, the ratio varying from approximately 3 when Y was 20 tons/sq.in. to 1 when Y was 120 tons/sq.in.—R. A. R.

The Use of Flat-Ended Projectiles for Determining Dynamic Yield Stress. III—Changes in Microstructure Caused by Deformation under Impact at High Striking Velocities. W. E. Carrington and Marie L. V. Gayler. (Proceedings of the Royal Society, Series A, 1948, vol. 194, Sept. 2, pp. 323–331). The mechanism of deformation of metals at high velocities has been studied by examining the microstructure of cylinders of mild steel, duralumin, and standard silver (of composition Ag 92·5%, Cu 7·5%) of similar hardness, and of steel balls after impact on steel plates at velocities from 300 to 3830 ft./sec.

The means by which the stress on impact was relieved depended on the material, and was first the formation of twins or "compression bands," *i.e.*, by block movement of wedges of material within individual grains, or by cracking. When the applied stress could no longer be relieved in this way, plastic deformation occurred.

The amount of residual strain in deformed mild steel and duralumin has been examined by observing changes of microstructure after annealing.

Hardness surveys were made on longitudinal sections of the cylinders and the results correlated with the microstructures and with observations of the limits of strain due to impact.

The Mechanics of the Tensile Test. E. Siebel and S. Schwaigerer. (Kaiser-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 145–152). It is shown how to determine the stress distribution in the necking zone of a specimen in the tensile test from the equilibrium of forces and the plastic conditions. A factor is derived for determining the fracture strength of steel in the undeformed state.—R. A. R.

The Elongation Behaviour at Low Temperatures of Some Austenitic Steels. K. Mathieu. (Kasier-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 169–173). Tensile tests were carried out at − 183° C. on three austenitic steels *A*, *B*, and *C* (*A* Cr 18%, Ni 8%; *B* Mn 17·6%, Cr 12·2%; *C* Mn 19·0%, Cr 1·2%, C 0·3%). A yield point with a distinct yield range was observed with steel *A*; simultaneous magnetic tests showed that the metal flow was closely associated with a γ–α transformation. There were also indications of a yield point with steel *B*, but it was not nearly so marked as with *A* and the transformation was also less marked. No yield point could be established for steel C which remained practically non-magnetic. The behaviour appeared to be due to increased deformability at the moment of phase transformation.—R. A. R.

Elastic Limit of Mild Steel. P. Laurent. (Bulletin du Cercle d'Études des Métaux, 1948, vol. 5, June, pp. 57–70). In this study of the stress-strain diagram for mild steel, the author discusses the different factors which are likely to modify the characteristics of the diagram. As far as the test is concerned consideration is given to the machine used for for the test, the speed of deformation of the test-piece, bend stresses, and the shape of the test-piece and its surface condition. The effect of heat-treatment and grain-growth of the metal on its tensile properties are also examined.—J. C. R.

Tensile Properties *vs* Composition of Double Normalized Cast Steel. H. A. Schwartz and W. K. Bock. (American Foundrymen's Association, 1948, Preprint No. 48-1). The authors have derived an equation for predicting the tensile strength of double normalized cast steel from its chemical composition. Only acid electric and basic open-hearth steels are considered.—R. E.

Impact Testing of Weldments. W. C. Long. (Metal Progress, 1948, vol. 54, July, pp. 43–45). An account is given of the method used at the Delco Products Division of the General Motors Corporation for the impact-testing of small welded assemblies used in the construction of shock absorbers for motor cars. A guillotine type of testing machine was used. Tests revealed that the impact energy absorbed, measured in ft.lb., and the appearance of the weld fracture were reliable indicators of general weld quality, fusion, porosity, ductility, and alignment in the electrodes.—R. E.

Residual Stresses in a Butt-Welded Structural I-Beam. W. J. Krefeld and E. C. Ingalls. (Welding Journal, 1948, vol. 27, Aug., pp. 417-s–420-s). As a supplement to a previous investigation of beams with butt-welded splices under impact (*see* Journ. I. and S.I., 1947, vol. 157, Dec., p. 644), the residual welding stresses in such a beam have been examined, electric strain gauges being employed. It is concluded that: (1) The distribution of stresses is similar to that found in other investigations of flat plates; (2) the greatest stresses were produced in the weld metal; and (3) the small premature departure from linear elastic behaviour observed in the original investigation in both static and dynamic tests could be attributed to the influence of plastic yielding in the weld metal resulting from the superposition of residual welding stress and stresses due to static or dynamic loads. J. P. S.

The Experimental Determination of the Beginning of Flow in Mild Steels under Impact-Type Loads. K. Fink. (Kaiser-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwessen, 1948, vol. 19, pp. 153–160). Apparatus was developed for studying the flow of metal in impact-tension and impact-compression tests in which a carbon resistance strain gauge with amplifier and cathode-ray oscillograph were used, after calibration in a static tensile test, to follow the change in force in time units of 10^{-4} sec. Tests on a mild steel showed an upper yield points more than twice the value of that in static tests. The upper yield point considerably exceeded the "dynamic" tensile strength which corresponds to the rate of deformation in the impact test. The relative increase in the yield points at equal loading velocities decreases with increasing carbon in the steel.—R. A. R.

An Impact Test for Cast Iron. A. B. Everest. (Association Technique de Fonderie, Oct. 1947: Fonderie, 1947, Dec., pp. 947–949: Nickel Bulletin, 1948, vol. 21, July, pp. 94–97). An account is given of the development of an impact test (now issued as British Standard 1349–1947) for cast iron. Details are given of the experiments made with different forms of test-piece to determine the most satisfactory one.

The test is carried out in an Izod machine and the final choice of test-piece was a 1·1-in. dia. bar grooved to a root dia. of 1·0 in., and a 0·798-in. plain bar with 22 mm. striking height.—J. C. R.

Dislocation Theory and Transient Creep. N. F. Mott and F. R. N. Nabarro. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 1–19). The authors put forward certain advances in the theory of dislocations, and discuss in particular their application to the theory of transient creep, in the sense in which the term is used by Andrade in 1911, 1914, and 1932, and by Orowan in 1947. R. A. R.

The Yield Point of a Metal. Sir Lawrence Bragg. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 26–29). The author expands the criterion he proposed for the onset of slip in a metal. In the author's treatment, the forces initiating and producing movement of a dislocation are ignored and an element of crystal, embedded in the matrix, is pictured as being strained together with the whole mass of metal. This treatment attempts to take account of the fact that the slip alters the state as it proceeds, so that one must consider the altered state in the region behind it as well as the pre-existing strain in the region it has not yet reached. It is probable that the relation :

$$\gamma_{\text{lim}} = \text{const. } s/t$$

where γ_{lim} is the shear strain at the elastic limit, s a whole interatomic distance, and t the dimension in each direction of a block of crystal, holds with a very similar value of the constant, of order unity, for a number of typical metals. R. A. R.

Effect of Solute Atoms on the Behaviour of Dislocations. A. H. Cottrell. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 30–38). It is shown that solute atoms differing in size from those of the solvent can relieve hydrostatic stresses in a crystal and will thus migrate to the regions where they can relieve the most stress. As a result they will cluster round dislocations forming 'atmospheres' similar to the ionic atmospheres of the Debye-Hückel theory of electrolytes. The conditions of formation of these atmospheres are examined and the theory is applied to problems of precipitation, creep, and the yield point.

Mechanical Effects of Carbon in Iron. F. R. N. Nabarro. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 38–45). Snoek has shown that when carbon atoms move from one possible set of interstitial sites in the lattice of α-iron to another set they cause shear strains. Cottrell has shown (*see* preceding abstract) that the stress around a dislocation may be relieved by the migration of solute atoms in its neighbourhood, and that the dislocation is then bound to its present position. By combining these theories with the usual theory of age-hardening it is possible to explain the existence of a yield point, quench-ageing, strain-ageing, delayed yield, and blue brittleness as consequences of the presence of carbon in iron. A rough quantitative theory of the time-ageing effects is given, and shown to agree with experiment. The need for further experiment is emphasized.

On Slip Bands as a Consequence of the Dynamic Behaviour of Dislocations. F. C. Frank. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 46–51). The movement of low-speed and high-speed dislocations through crystals is examined, and it is found that if dislocations can attain velocities approaching that of sound, then their reflection at free boundaries, and their cross-over in the interior, is to be expected ; the consequence of these processes appears to be the development of slip bands in a manner very similar to that which is observed.—R. A. R.

Work-Hardening in Polycrystalline Pure Metals. R. L. Woolley. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 51–56). Observation of the plastic deformation of metals when the direction of stressing is reversed gives additional means of checking various theories of work-hardening. Experimental results for copper can be explained on each of three theories (the exhaustion, the hardening, and the crystallite-size theories), suitably modified. The exhaustion theory gives the clearest physical picture. The possibility of a combination of the three processes is not excluded.

Deformation of Crystals by the Motion of Single Ions. F. R. N. Nabarro. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 75–90). A homogeneous stress exerts no force on a vacant lattice site or interstitial ion, and previous estimates of the rate of deformation of a solid due to the migration of lattice defects under stress must be rejected. The forces acting on the surfaces of a specimen alter the concentrations of defects which would be present in thermodynamical equilibrium near these surfaces, and the diffusion of defects through the lattice from one part of the surface to another under the resulting concentration gradient leads to a rate of creep which depends on the size of the specimen. The assumption of a mosaic structure removes many of the difficulties, but micro-creep in tin cannot be explained by such a mechanism, because thermal agitation would prevent the establishment of a limiting total strain independent of the stress. The magnitude of the effect is calculated for ionic crystals near their melting points and found to be too small to account for the observed rates of sintering.

Mechanisms of creep under non-uniform stress are discussed, and their order of magnitude is estimated. Finally, a general survey is given of the creep phenomena to be expected in a metal under intense neutron bombardment as a result of the motion of interstitial ions and of the vacant lattice sites from which they have been ejected.

Thermoelectric Properties of Metals—Influence of Cold Work and Impurities. C. Crussard. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 119–133). The effect of deformation on the thermoelectric power of metals near room temperature has been investigated. It can be considered under two headings, elastic and plastic. For non-magnetic metals the elastic deformation is proportional to stress ; for magnetic metals the results are erratic and very sensitive to magnetic influences and to impurities. The action of impurities in a metal on its thermoelectric power offers a very sensitive method for determining the state (dissolved or precipitated) of minute amounts of foreign atoms.—R. A. R.

Recovery and Recrystallization as Processes of Dissolution and Movement of Dislocations. W. G. Burgers. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 134–137). This paper summarizes the accounts already published in *Proceedings of the Royal Academy of Science, Amsterdam* by the author on (*a*) recovery *versus* recrystallization in their dependence on time and temperature of heating, (*b*) block structure of the crystalline state, and (*c*) dissolution and movement of dislocations under heat-treatment. Comments are also made on M. Cook and T. Ll. Richards' paper dealing with recrystallization in copper. R. A. R.

The Rate of Approach to the Ordered State in Alloys. L. Weil. (Physical Society : Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 138–140). It is shown that the rate of approach to the ordered state in alloys such as platinum–iron is greatly increased if they are produced in powdered form by the reduction of platinocyanides. This is cited as evidence that diffusion in alloys is due to the motion of vacant lattice points or of similar imperfections.

The Meaning and Measurement of Transition Temperature. R. D. Stout and L. J. McGeady. (Welding Journal, 1948, vol. 27, June, pp. 299-s–302-s). The choice of specimen is far less critical to correlation of test methods than is the choice of the criterion used to establish the temperature of transition from tough to brittle fracture. Various test methods do not necessarily measure the same property of the steel, and some are far more sensitive than others to the shape of the specimen.—J. P. S.

Laboratory Measurements of Stress Distribution in Reinforcing Steel. D. McHenry and W. T. Walker. (Journal of the American Concrete Institute, 1948, vol. 19, June, pp. 1041–1054 : [Abstract] Metals Review, 1948, vol. 21, Aug., p. 56). Typical laboratory test results on stress distribution of simple reinforced beams are given before and after cracking and compared with those computed by conventional methods. Possible applications of the gauging method as well as its limitations are reviewed.

Concerning Stress Conditions in a Round Iron Plate with Definite Crystal Structure during Deep Drawing. Part I. K. V. Grigorov. (Journal of Technical Physics, U.S.S.R.,

1948, vol. 18, Feb., pp. 175–186 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, Aug., p. 56). The azimuthal distribution of stresses was calculated for different types of crystal structures. It was found to be highly anisotropic and independent of structure.

The Determination of Stresses during Plastic Twisting. N. N. Davidenkov, N. G. Mokievskaya and M. N. Timofeeva. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 720–727). [In Russian]. An experimental investigation is described in which stresses developed during the plastic twisting of steel specimens were studied, the results confirming the formula of Ludwig.—S. K.

The Determination of Internal Stresses. W. Soete. (Metalen, 1948, vol. 2, July, pp. 232–245). [In Dutch]. After a discussion of residual stresses in steel, in particular after welding, a method of determining them at increasing depths below the surface is described. Three resistance strain gauges are placed radially and a small hole is drilled at the focal point. The changes in strain are measured as the drilling proceeds. The calculations involved are explained. (*See* Journ. I. and S.I., 1948, vol. 159, July, p. 338).—R. A. R.

Plastic Flow in Cast Iron at Room and Elevated Temperatures, with Special Reference to Relief of Stress. C. R. Tottle. (Institute of British Foundrymen, June 8–11, 1948, Paper No. 900). The author considers the deformation characteristics of cast iron, especially in the relation between elastic and plastic flow, to be susceptible to considerable variations, according to the mode and speed of application of stress. The total deformation arising from any test at room temperature can be increased, and the ratio 'elastic' to 'plastic' decreased, merely by slow loading, or periods of ageing between successive increments of stress. The distinction between 'brittle' and 'ductile' materials is not so marked, therefore, when slow rates of stressing are used. The experimental method used is that of stress-free bars loaded in transverse bending, followed by study of the plastic flow taking place with time. Incremental stressing gives perfect translation of elastic into plastic deformation in remarkably short periods of time at room temperature, resulting in severely deformed cast-iron bars, normally unobtainable in routine testing. The influence of this 'ageing' under stress is considered in 'weathering' as a form of stress-relief treatment. At elevated temperatures, the rates of flow and the total deformation are naturally much increased, and the application to stress relief shows that high temperatures of the order of 450° to 500° C. are necessary for high-duty unalloyed iron, and 550° to 650° C. in the case of alloy additions, where 70% relief and upwards is desired. Creep curves confirm the tests on relief of stress, and enable correlation of time, temperature, and deformation to be made for several compositions and types of high-duty cast irons.

X-Ray Unit for Stress Analysis. (Instruments, 1947, vol. 20, Sept., p. 836: [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Apr., p. 72). This apparatus, which is described, enables residual stresses in welded plates in naval construction, to be localized; it can be used to detect fatigue cracks in bridges.

The Cinematography of X-Ray Interferences. H. Neerfeld. (Kaiser-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 181–185). In fine-structure tubes with a small focal spot it is not always necessary to have an iris aperture on the camera. It is thus possible to illuminate a larger area of the surface and, by attention to the focusing conditions, to shorten the exposure time considerably. The broadening of the interference lines using flat surfaces with large and small glancing angles was studied using α-iron as an example. With back-reflection the conditions were in such cases so favourable that, even with very large surfaces, there was very little broadening. With oblique radiation the broadening was symmetrical to the centre so that the position of the line was unchanged. The photographic process was therefore very suitable for studying rapid changes in distances between atomic layers. An apparatus is described for taking continuous photographs at a constant rate of the glancing angle and the atomic distances. The apparatus was applied to the study of changes in the glancing angle while heating an aluminium sheet and during a tensile test on a steel specimen. The tensile test showed that interference lines maintained their sharpness and intensity beyond the mechanically recognizable yield point, and then suddenly became diffuse and weak without any noticeable shift.—R. A. R.

The Application of Interference Counters to X-Ray Stress Determinations. H. Möller and H. Neerfeld. (Kaiser-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 187–190). A study was made, with an apparatus developed by the Reichsröntgenstelle, of the limits within which interference counters can be used for X-ray stress determinations. Counter-current curves were recorded for the $\{310\}$ interferences with cobalt-Kα radiation and for the $\{211\}$ interference with chromium Kα radiation on α-iron. These curves were compared with those obtained by photometry. With cobalt radiation the former curves could be evaluated just as accurately as with the latter, so that lattice constants could be determined with an accuracy of about 7×10^{-5} Å. With chromium radiation the counter curve is more uncertain than the photometer curve. The true position of the interference lines, and especially the maximum intensity, can be found by taking the mean of the two curves obtained by a to-and-fro movement of the counter. Practical application to stress determination in a bend test on mild steel gave results which, in the elastic range, agreed well with those calculated from the deformation and specimen dimensions. The main advantage of the interference counter is the saving in time as compared with preparing films and subsequent photometry. The disadvantage is the rather elaborate apparatus which is not easily transported. R. A. R.

Basic Physical Properties Relied upon in the Frozen Stress Technique. W. A. P. Fisher. (Proceedings of the Institution of Mechanical Engineers, 1948, vol. 158, Sept., pp. 230–235). The theory of the use of thermo-setting resins having photoelastic properties for solving problems of three-dimensional stress is explained and results obtained with Glyptal resin and glass-clear phenol-formaldehyde resin (Catalin 800) are described. The properties of both are compared, and troubles such as 'rind effect' are discussed. Careful tests have shown that, when suitably cured, Catalin 800 can give reliable results, but that 'rind effect' is still a serious drawback.—R. A. R.

Modern Applications of Photo-Elasticity. R. B. Heywood. (Proceedings of the Institution of Mechanical Engineers, 1948, vol. 158, Sept., pp. 235–250). Recent important developments in the application of photoelasticity to engineering and the method of preparing transparent models for stress analysis are described, and the significance of the photoelastic fringes is explained. The three-dimensional 'freezing' technique is described; this enables an assessment of the elastic distortions to be made. In a written communication L. Foeppl and E. Moench described their method of overcoming the 'rind effect,' which was by smearing the resin with oil and covering it with aluminium foil not more than 0·01 mm. thick. Resin models thus protected were preserved for several weeks without edge stresses and could be heat-treated without the slightest disturbance by rind effect.—R. A. R.

Dislocation Theory of the Fatigue of Metals. E. S. Machlin. (National Advisory Committee for Aeronautics, 1948, Jan., Technical Note No. 1489, pp. 1–33: [Abstract] Applied Mechanics Review, 1948, vol. 1, May, p. 142). The author develops a theory of fatigue failure for annealed solid solutions based on dislocation theory. This is done by assuming the prior existence of submicroscopic cracks, and postulating certain arbitrary assumptions regarding the nature of the dislocations generated at the ends of the cracks during the stress cycles. The rate of generation of dislocations, obtained from a previous paper by the author and A. S. Nowick, is identified with the net rate of growth per crack, and leads to a semilogarithmic relation between the number of cycles to fracture and the maximum tensile stress of the cycle, for stresses above the so-called endurance limit. The temperature dependence of the process is indicated. It is assumed throughout that no structural changes take place in the material and that in each cycle the same analysis may be applied.

Effect of Residual Tension Stress on the Fatigue Strength of Mild Steel. L. ↄ. Hall and E. R. Parker. (Welding Journal, 1948, vol. 27, Aug., pp. 421-s–425-s). As a result of fatigue tests on specimens having residual stresses imposed by the laying down of weld beads, it is concluded that residual stresses can exist in certain conditions in welded structures

without decreasing the fatigue strength of the material. However, unwelded but sharply notched specimens having residual tensile stresses at the bottom of the notch have greatly reduced fatigue limits; where the residual stresses are compressive, the fatigue limit is slightly higher than specimens having no residual stress.—J. P. S.

Contribution on the Determination of the Fatigue Limit. A. I. Kochetov and A. D. Krolevetskii. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 732–738). [In Russian]. A procedure is proposed for the determination of the fatigue limit and a statistical treatment is made of the results obtained experimentally.—S. K.

A Machine of Small Bulk for Testing for Prolonged Endurance. M. L. Bernshtein. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 760–761). [In Russian]. A machine in which tests of prolonged endurance can be carried out at high temperatures is described. The height, length, and width of the machine are 565, 530, and 360 mm., respectively.—S. K.

A New Machine for Fatigue-testing. S. I. Yatskevich. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 739–741. [In Russian]. An account is given of a machine for fatigue testing which works as a cantilever machine, loaded at its free end. The specimen is rotated while the direction and magnitude of the load remain constant.—S. K.

Additional Stresses in Fatigue Specimens. S. G. Kheifets. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 742–748). [In Russian]. The design of cantilever fatigue-testing machines is discussed and the additional stresses arising in specimens subjected to fatigue tests are considered.—S. K.

Shotpeening. F. K. Landecker. (Transactions of the Society of Automotive Engineers, 1948, vol. 2, Apr., p. 191: [Abstract] Journal of the British Shipbuilding Research Association, 1948, vol. 3, Sept., p. 393). Many examples are given, illustrating the improvement to be obtained in the fatigue life of car components subject to fatigue, shock, or impact, by the process of shotpeening. This process, which causes plastic flow of the surface layers, sets up a high residual compressive stress in the surface. The depth of the layer cold-forged in this way varies from 0·005 to 0·015 in., depending on the material and intensity of peening. It is important that the correct combination of such variables as shot size, nozzle size, and air pressure or wheel speed be used. The shot used should never be more than half the radius of the smallest fillet or corner. An Almen gauge is described, which can be used to measure the intensity of peening. Its operation is based on the measurement of the curvature of a standard steel strip, which has been subjected to the same cycle of operations as the part to be treated, and then shotpeened on one side while bolted to a block. Curves obtained by plotting Almen arc height against time of exposure to peening show that a state of saturation is obtained after a definite time, the curve becoming parallel to the time axis. In the author's experience it is essential that the treatment should be carried to saturation, but no ill-effects accrue if it is continued beyond this point. Although light lapping or honing has frequently been found to be beneficial after shotpeening, if the lapping is taken too far the advantages of the process may be lost. The thin compressive surface will be destroyed by grinding or machining.

The Nature of the Hardness and the Strength of Metals and Alloys. S. T. Kishkin and R. L. Petrusevich. (Bulletin de l'Academie des Sciences de l'U.R.S.S., Classe des Sciences Techniques, 1947, pp. 749–759: Chemical Abstracts, 1948, vol. 42, Sep. 10, col. 6295–6296).

Dynamic Hot Hardness Testing. G. M. Enos, G. J. Peer, and J. C. Holzwarth. (Metal Progress, 1948, vol. 54, July, pp. 51–55). Particulars are given of a simple spring-loaded punch hardness tester, and its use in determining S-curves, by changes in hot-hardness of an oil-hardening tool steel (0·75% C, 1·00% Cr, 1·75% Ni), and an S.A.E. 52100 steel. The method offers a rapid means of determining the isothermal transformation characteristics of oil-hardening and air-hardening steels below 1000° F. The method is not readily applicable to steels the transformation of which begins in much less than 15 sec., although an impression could be made in 6 sec.—R. E.

Critical Study of the Formula $R = K\Delta$ Relative to Steels. E. Jadot. (Revue Générale des Ingénieurs Techniques, 1947, vol. 1, Jan.–Feb., pp. 75–84: [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Apr., p. 47). This is a critical examination of variations in the coefficient of the ratio (K) between the breaking load and Brinell hardness in the case of ordinary and special steels. A systematic study is presented of the influence of composition, heat-treatment, and mechanical treatment on K.

Hardenability of Constructional Steels. W. Steven. (Journal of the Birmingham Metallurgical Society, 1948, vol. 28, Sept., pp. 169–196). The author surveys the "Hardenability Symposium" (Iron and Steel Institute, Special Report No. 36) and summarizes present knowledge of the various phases of the subject.—R. A. R.

Application of Hardenability Requirements in the Steel Foundry. C. Vennerholm. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 824–836). The author defines hardenability and discusses the Jominy end-quench test and the mechanism of hardenability. Factors affecting the transformation of austenite to martensite are also dealt with.—R. E.

A Simple Method for Finding the Dynamic Hardness of Metals with the Help of a Double-Pointed Cone. F. F. Vitman and B. S. Ioffe. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 727–732). [In Russian]. The determination of dynamic hardness by using a double-pointed cone, one point of which impinges on a standard specimen while the other impinges on the specimen under test, is described.—S. K.

The Rockwell Hardness of Meteorites. J. D. Buddhue. (Popular Astronomy, 1947, vol. 55, pp. 550–556: Chemical Abstracts, 1948, vol. 42, Aug. 10, col. 5393). Data are given for 22 nickel-iron meteorites at room temperature and also for 14 tests in which specimens were heat-treated at various temperatures.

Ageing of Mild Steel after Straining. P. Laurent. (Bulletin du Cercle d'Études des Métaux, 1948, vol. 5, June, pp. 71–81). This study of the factors influencing the ageing of mild steel after straining includes the influence of the rate of straining, the duration and temperature at which ageing occurs, and the influence of chemical composition. An outline is given of some theories attempting to explain the phenomena of ageing.—J. C. R.

Temper Brittleness in Boiler Steels and Rail Steels. W. J. Holtman and W. C. Keil. (Quarterly of the Colorado School of Mines, 1947, vol. 42, No. 2). Specimens of boiler steel (C 0·15–0·21%) and rail steel (C 0·70–0·80%) were tested to determine sensitivity to temper brittleness. Specimens of boiler steels were hardened and tempered at 650° C. for 1 hr. Some were quenched in water after tempering and others cooled at 18° C./hr. from 600° to 400° C. Izod impact tests were then made at room temperature and at temperatures in the range +400° F. to −80° F. The rail-steel specimens were tempered without previous hardening treatment, some being oil-quenched and others cooled slowly. The impact strength of the boiler steels was lower when tempered at 600° C. and slowly cooled than when quenched, and the drop in the impact values was marked in the testing-temperature range 0° to −60° F. Very little, if any, evidence was found of temper brittleness in the rail steels. When the rail steels were tempered at 550° C. for 4 hr. the impact values were very greatly increased. The microstructure of embrittled specimens of boiler steel revealed a grain-boundary precipitate. R. A. R.

Wear. A. Leon. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1948, vol. 3, Aug. 15, pp. 211–214). The causes of wear and methods of measuring the wear of metals are reviewed.—R. A. R.

Influence of Relaxation and Recrystallization on the Magnetic Properties of Soft Magnetic Materials. V. I. Drozhzhina, M. G. Luzhinskaya, and Ya. S. Shur. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Feb., pp. 167–174 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, Aug., p. 8). An account is given of an investigation of transformer steel (96% Fe, 4% Si) and of molybdenum permalloy (78·5% Ni, 4% Mo, 17·5% Fe), showing effects of different degrees of deformation and of different heat-treating schedules.

Concerning Changes of Electrical Conductivity in a Magnetic Field (Thompson Effect) in Alloys Having High Coercive Force. V. I. Drozhzhina and Ya. S. Shur. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Feb., pp. 149–152). [In Russian].

Concerning Peculiarities of the Variation of Electrical Conductivity of Several Ferromagnetic Alloys in a Magnetic

Field. S. V. Vonsovskii. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Feb., pp. 145–148). [In Russian].

Influence of Austenite on the Magnetization Curve of Steel. V. V. Parfenov and R. I. Yanus. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Feb., pp. 161–166 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, Aug., p. 8). The authors discuss the magnetization of tempered chromium–manganese steel with austenite contents up to 74% in fields of 20 to 12,000 oersteds. The proportionality between magnetization and final concentration of the ferromagnetic phase exists to a great extent for fields of medium magnetic resistance as well as for high-resistance fields.

Magnetic Properties of Chromium–Nickel–Molybdenum Steels after Different Heat Treatments. P. N. Zhukova and M. N. Mikheev. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, Feb., pp. 187–196). [In Russian].

Iron–Silicon–Nickel Alloy Having a Constant Permeability. T. Yamamoto. (Journal of the Institute of Electrical Engineers of Japan, 1943, vol. 63, p. 613 : British Abstracts, 1948, BI, Aug., col. 414). Permeability curves and hysteresis loops were obtained for the iron alloy with silicon 10·82% and nickel 18·23%. Permeability at $<0{\cdot}75$ oersted is approximately constant. Hysteresis loss is small in a range of constant permeability. Permeability curves are also given for alloys of slightly different composition.

Magnetic Properties of Iron–Silicon–Nickel Alloy Cooled in the Magnetic Field. T. Yamato. (Journal of the Institute of Electrical Engineers of Japan, 1944, vol. 64, pp. 278–279 : British Abstracts, 1948, BI, Aug., col. 414). The maximum permeability of the 10·5/16/73·5 silicon–nickel–iron alloy (2900) is increased to 36,000 by cooling in a field of 15 oersteds at 700° and the **S**-shaped hysteresis loop is changed to the square form. Magnetic cooling has the most marked effect on permeability with the 10/16/74 alloy. Magnetostriction is very small.

Magnetostriction of Silicon-Steel Sheet. S. Wada and H. Nakae. (Journal of the Institute of Electrical Engineers of Japan, 1943, vol. 63, p. 202 : British Abstracts, 1948, BI, Aug., col. 414). The magnetostriction of fine steels containing 4%, 3·4%, 3%, and 1·5% of silicon and 0·02% of carbon respectively, was measured. Silicon-steel sheet does not undergo an inversion of magnetostriction under a high magnetizing field as does pure steel sheet.

Effect of Heat Treatment on Magnetic Properties of " Senperm " Alloy. T. Yamato. (Journal of the Institute of Electrical Engineers of Japan, 1944, vol. 64, pp. 12–17 : British Abstracts, 1948, BI, Aug., col. 414). Senperm alloy (Fe with Si about 11%, Ni 16%) has an initial permeability, maximum permeability, and hysteresis loss, respectively, of 230, 3300, and 36·9 ergs per c.c. per cycle in the annealed state and 750, 5500, and 9·68 ergs per c.c. per cycle after quenching from 550°. The 11/16 silicon–nickel alloy in the cast state contains both body- and face-centred cubic constituents (α 2·81 and 4·06, respectively). The regular lattice structure appears only after gradual cooling from 400° to 200°.

The Significance of the Magnetic Characteristics in the Estimation of Hard-Metal Alloys. H. Franssen. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 85–89).

The Idealized Curve—A New Magnetic Parameter. H. Lange. (Kaiser-Wilhelm-Institut für Eisenforschung : Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 191–195). If, for a given field strength H_a, the ideal magnetization I_i commencing from an initial magnetic state (H_aI_a) is determined, this would, in a sense, correspond to a sudden change in magnetization $I_i - I_a$, at a constant field strength H_a. This sudden jump can be split up into any desired number of smaller and equal steps to each of which a magnetic field strength of alternating-field amplitude H_w can be assigned. A curve called the ' idealized curve,' showing the increase in magnetization in relation to the alternating field amplitude, can then be constructed. This curve characterizes the initial magnetic state. Its slope at the starting point is equal to the irreversible magnetic susceptibility.—R. A. R.

Magnetic Amplifiers Improved by New Alloy. (Instruments, 1948, vol. 21, June, p. 544 : [Abstract] Bulletin of the British Scientific Instrument Research Association, 1948, vol. 3, Sept., p. 260). This brief note records the fact that Permenorm 500-Z has been successfully produced at the U.S. Naval Ordnance Laboratory, White Oak, Md. This magnetic nickel–iron alloy, first synthesized in Germany in 1943, has important applications in the manufacture of magnetic amplifiers.

The Magnetizing Process in the Case of an Iron–Nickel–Aluminium–Cobalt–Copper Alloy with Preferred Orientation. W. Jellinghaus. (Zeitschrift für Metallkunde, 1948, vol. 39, Feb., pp. 52–56). The magnetization curves were constructed with field strengths increasing from −500 to +500 oersteds for two iron alloys of similar composition (approximately C 0·04%, Co 22·4%, Ni 15·1%, Al 8·1%, Cu 3·9%). Commencing with the completely non-magnetic condition, internal magnetization curves were obtained in weak fields which, when $H_{max.}$ was less that H_c, showed less magnetization in the preferred than in the transverse direction, and *vice versa* when $H_{max.}$ was greater than H_c. In the transverse direction there was no appreciable permanent magnetism even with a very strong field.—R. A. R.

Castings Industry Applications of Magnetic Particle Inspection. W. E. Thomas. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 482–489). The methods of magnetic particle inspection are described and its application to foundry practice is discussed. A practical example of magnetic inspection of cylinder barrels is described.—R. F. F.

Magnetic Examination of Welds. A. Gaubert. (Soudure et Techniques Connexes, 1947, vol. 1, July–Aug., pp. 137–152).

Electrical Resistance of Iron–Chromium–Carbon Alloys at High Temperatures. M. E. Blanter. (Journal of Technical Physics (U.S.S.R.), 1947, vol. 17, pp. 549–556). [In Russian].

A New Metallurgical Research Tool. The Heat and Mass Flow Analyzer. J. de Laclémandière. (Métallurgie, 1948, vol. 80, July, pp. 11, 13–15, 17, 19). A detailed account is presented of a heat and mass flow analyser installed at Columbia University in America. Because of the analogy between the flow of heat and electricity, this electrical machine enables various heat-flow problems to be studied. (*See* Journ. I. and S.I., 1946, No. I, p. 72A, and 1948, vol. 158, Mar., p. 392).

Surface Testing by Acoustic Means. (Oil Engine, 1948, vol. 16, Aug., p. 119 : [Abstract] Journal of the British Shipbuilding Research Association, 1948, vol. 3, Sept., p. 394). The Capac Co., has developed an inexpensive stethoscopic device for testing the surface finish of a mechanical component. The device consists of the Capac Bin-aural equipment, including a Tectoscope fitted with a test rod terminating in a steel wall $\frac{1}{4}$-in. in. dia. A stroking motion at right angles to the direction of the grinding or other finishing process produces a noise which varies widely according to the roughness of the surface.

Some Crack Detection Methods. H. Manley. (Metallurgia, 1948, vol. 38, July, pp. 165–168). Some of the methods more generally used for the detection of flaws in ingots, forgings, castings, and other metal products are briefly reviewed.—P. W.

A Portable Ultrasonic Thickness Gage. D. J. Evans. (Non-Destructive Testing, 1948, vol. 6, Spring Issue, pp. 22–24, 42). A description is given of the " Audigage " thickness-testing instrument. With this the material under test is set into a resonant vibration condition. When there is a resonance condition of the ultrasonic wave in the material, the travel time of the wave through the material and back is equal to the period of the applied wave, or a harmonic, so that when the period of applied wave is adjusted to a point where it is equal to the travel time, the frequency is then a measure of the thickness. The instrument is designed for a thickness range of $\frac{1}{8}$ to 12 in. of steel. It is portable and can be used on structures accessible from only one side.—R. A. R.

Importance of Radiography to Inspection. E. L. LaGrelius. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 375–380). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 293.

A New Method for the Construction of the Darkening Curve for X-Rays. V. N. Protopopov. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 687–692). [In Russian]. A new graphical method is proposed for the determination of the relative intensities of lines in X-ray spectra.—S. K.

Cameras for X-Ray Structural Analysis of Monocrystals. Yu. A. Bagaryatskii and M. M. Umanskii. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 693–702). [In Russian]. The principles and construction of a number of cameras used in the U.S.S.R. for X-ray studies of crystal structure are described and the orientation of monocrystals is considered.

Orientation of Crystals with the Aid of a Goniometric Head. Yu. A. Bagaryatskii. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 703–709). [In Russian]. The goniometric orientation of crystals for X-ray investigations of their structure is considered theoretically and equations governing such orientations are deduced.—S. K.

Comparing the Decrease in Strength with Time with X-Ray Pictures during the Recovery and Recrystallization of Cold-Strained Soft Iron. G. Niebch and H. Neerfeld. (Kaiser-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 175–179). The changes taking place during the annealing of cold-strained soft iron were studied using hardness tests and X-ray back-reflection diagrams. Whereas optical observation of the structural changes is rather crude, the X-ray technique enabled these changes to be followed accurately, in particular, each stage of recrystallization could be noted. It was found that large grains were formed, not by the combining of smaller previously recrystallized grains, but that they grew practically instantaneously out of the matrix.—R. A. R.

Acceptance Standards in Radiographic Inspection. C. Croxson. (Institute of Physics, Industrial Radiology Group, Symposium: Welding, 1948, vol. 16, Aug., pp. 324–329). A critical review is made of known standards or codes used in industry for assessing the quality of materials by radiographic examination.—R. A. R.

Radioactive Isotopes As Sources in Industrial Radiography. G. H. Tenney. (Non-Destructive Testing, 1948, vol. 6, Spring Issue, pp. 7–10). The theory of atomic structure is explained, some of the work with radioactive isotopes is reviewed, and preliminary experiments with the radioactive isotope Lanthanium on a steel cut in steps of increasing thickness from $\frac{3}{4}$ to $5\frac{1}{4}$ in. are described. Exposure-thickness curves were obtained which indicated that this source could be used for industrial radiography.—R. A. R.

Gamma-Ray Radiography in a Steel Foundry. R. A. Willey. (Non-Destructive Testing, 1948, vol. 6, Spring Issue, pp. 15–18). Examples of the use of gamma-ray radiography in a steel foundry are quoted which show that the apparatus originally installed to test castings in accordance with American Navy Department requirements has now become a production control tool.—R. A. R.

Influence of Field Size on Contrast and Exposure in Industrial Radiography. E. D. Trout and A. L. Pace. (Non-Destructive Testing, 1948, vol. 6, Spring Issue, pp. 19–21). Experiments are reported relating to the intensity of X-ray beams which can be used under certain conditions without scatter, estimates of scatter for various voltages and field sizes, and the extent to which scattered radiation influences the film density for long narrow fields.—R. A. R.

Weldography, Radiographic Weld Control for Pipe Line Construction. W. W. Offner. (Non Destructive Testing, 1948, vol. 6, Spring Issue, pp. 40–42). The procedure developed for the X-ray inspection of butt welds in large oil pipe lines is described.—R. A. R.

The Creep of Metals. E. N. da C. Andrade. (Physical Society: Report of a Conference on Strength of Solids, Bristol, July, 1947, pp. 20–26). Three forms of apparatus for studying creep are described. The third, now being prepared, enables creep at homogeneous shear to be studied. The differences between metal flow at constant load and constant stress are examined and a formula for length at any time in a flow test is given. In constant-load tests the last stage of flow is at an increasing rate which, in most cases, is a consequence of increase of stress, but in the case of a steel high in nickel and chromium at 800° C. is due to structural changes taking place in the steel during flow. There are three distinct types of structural change: (*a*) Crystal recovery, which manifests itself by a softening of the metal with no microscopically detectable change in structure; (*b*) true recrystallization, manifested by a movement of crystal boundaries; and (*c*) martensitic phase change. Finally, the mechanism of the flow, in particular the physical distinction between a rapidly decreasing rate flow (β flow) and permanent or viscous flow (K flow) is considered.

High Creep Strength Austenitic Steel Tubes. G. T. Harris and W. H. Bailey. (Metallurgia, 1948, vol. 38, Aug., pp. 189–192). The development and properties of steel tubes in Jessop G.18B. steel (C 0·4%, Mn 0·8%, Si 1·0%, Ni 13·0%, Cr 13·0%, W 2·5%, Mo 2·0%, Cb 3·0%, Co 10·0%) are described. Billets were extruded at 1240° C. to form hollows. These, after softening by cooling in air from 1120° C., were cold drawn in three or four passes to the finished size with an annealing treatment after the first two passes. Good welding properties and high creep resistance were obtained. Such tubes are intended for use in air heaters and heat exchangers in large gas-turbine installations.—R. A. R.

Sheet Metals for High Temperature Service. P. A. Haythorne. (Iron Age, 1948, vol. 162, Sept. 23, pp. 89–95). The resistance to flame impingement of a number of heat-resisting alloys used in gas turbines has been examined by rotating tubular specimens at 1 r.p.m. while an eight-pointed oxygen/natural-gas flame impinges on the interior surface. The temperatures reached depend on thermal conductivity, emissivity and radiation losses, and severe temperature gradients exist, especially in low-conductivity materials such as Inconel X, S-816, Vitallium, Hastelloy C, and N-155, which lead to failure through distortion after a number of cycles of 5 min. heating followed by 1 min. cooling in air. It is concluded that cladding with higher-conductivity materials will be advantageous in conditions where severe flame impingement occurs.—J. P. S.

Creep Tests on Some Heat-Resisting and High-Pressure-Hydrogen-Resistant Steels. H. Kiessler. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 45–48). The results of tensile, impact, and creep tests on eleven low alloy steels containing chromium, vanadium, and molybdenum (two with nickel and two with 0·56% of tungsten) are reported. An increase in the tempering temperature improved the creep resistance. Although the notched-bar toughness in the heat-treated state was lower after cooling in air, the creep resistance was greater than after oil-quenching. At 550° C. the stress-time curves were steeper, and at 400° C. flatter than at 500° C. Stressing in service for 11,000 hr. followed by treatment at 600° C. had no noticeable effect on the creep resistance of bolts.—R. A. R.

Tests on Chromium-Free Heat-Resisting Steels. W. Völker. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 49–54). Tests were carried out to determine whether steels for service at 800–1000° C. could be prepared by alloying with aluminium, silicon, titanium, and manganese, but no chromium. Steels with 10% of aluminium, or more than 3% of silicon, or 1·5% of titanium were too brittle. Compositions suitable for the above service appeared to lie within the following limits: Aluminium 3·5–7%, silicon 0·50–2·5%, titanium up to 1% and carbon as low as possible; these steels are ferritic. An austenitic-ferritic steel which was scale-free up to 800° C. with high strength and good weldability had the composition silicon 1·4%, manganese 17·0%, aluminium 4·6%, and no chromium.—R. A. R.

Relationships between the Constitutional Diagram and the Mechanical Properties, in Particular, the Creep Behaviour of Iron–Niobium and Iron–Titanium Alloys. W. Peter and W. A. Fischer. (Kaiser-Wilhelm-Institut für Eisenforschung: Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 161–168). The mechanical properties at room temperature and the creep strength at 500° C. of iron–niobium alloys (Nb 0·14% to 8·8%) and iron–titanium alloys (Ti 0·05% to 0·92%), hardened from 1000–1300° C. and tempered at 500° C. were determined. The relationship between the properties as reported by W. Holtman, and by P. Bardenheuer and W. A. Fischer, was confirmed. The work was extended by determining for each hardening temperature the maximum values for these properties of compositions which at that temperature were at the boundary of the γ-field. For high quenching temperatures the composition for the optimum properties moves towards less alloying elements after the maximum width of the γ field has been passed. The optimum properties for niobium–iron (Nb 0·7%) quenched from 1300° C. and tempered at 600° C. for 1 hr. were 83 kg./sq. mm. tensile strength at room temperature and 50 kg./sq. mm. creep strength at 500° C. The equivalent values for a similarly heat-treated titanium–iron alloy (Ti 0·38%) were 65 and 38 kg./sq. mm. respectively.—R. A. R.

A Comparison of Some Carbon Molybdenum Steels on the Basis of Various Creep Limits. A. E. Johnson and H. J. Tapsell. (Institution of Mechanical Engineers, Aug., 1948, Advance Copy). The results of creep tests on six carbon–molybdenum steels, which are presented and discussed, indicate similar limitation, in the applicability of short-time

creep limits to estimation of design stresses, for long-time service as was disclosed by earlier tests on carbon steels (*see* Journ. I. and S.I., 1946, No. I, p. 81A). The diversity in creep characteristics of the molybdenum steels makes it impossible to define a short-time creep test which will effectively evaluate working stresses at temperatures between 500° and 600° C. giving the same assurance of long life (10^4–10^5 hr.) for a specified permissible creep.—R. A. R.

Choosing Heat Resisting Materials. E. Barber. (Machinery Lloyd, 1948, vol. 20, May 15, pp. 62–65 : [Abstract] PERA Bulletin, 1948, vol. 1, Aug., p. 609). The qualities required in heat-resisting materials are listed and the influence of different alloying elements on these qualities is discussed. The types of alloys available to the user are considered and the properties of each of these types are mentioned.

Effect of Copper Addition Contaminants on Mechanical Properties of Gray Cast Iron. K. E. Rose and C. H. Lorig. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 89–101). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 308.

Influence of Selenium on Sulphide Inclusions and Ductility of Cast Steel. A. P. Gagnebin. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 277–287). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 143.

The Capacity of the Austenitic Manganese Steels to Increase Their Strength. H. Schottky. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 55–64). The literature on the properties of austenitic manganese steels is reviewed with particular reference to the effects of manganese and carbon on the tensile properties, and the effects of cold work.—R. A. R.

The Effect of Chromium, Manganese, Carbon, and Phosphorus on the Temper Brittleness and Hot Brittleness of Steel. W. Bischof and Lieselotte Böttger. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 29–44). The tendency to temper brittleness of a large number of melts of steel containing from 0·01% to 0·61% of carbon and chromium increasing up to 12%, oil-quenched from 950°, tempered at 650°, and with and without annealing at 500° C. for periods of 100, 500, and 1000 hr. was investigated by impact and Brinell tests. Up to 12% of chromium has no effect on the temper brittleness or fall in impact value after annealing of steels low in carbon, phosphorus, and manganese; additions of these elements increase the temper brittleness; increasing the chromium at the same time from about 1–1·5% to 3–5% lowers the impact strength to a minimum, whilst further increases in chromium to 12% decrease the brittleness. Increasing the manganese beyond 1–1·5% has an embrittling effect. Raising the carbon in chromium and manganese steels to about 0·3% increases the brittleness, but above this the effect is reversed; this effect is less with chromium than with manganese steels. A high phosphorus content embrittles low-carbon low-manganese chromium steels. The rate of embrittlement of chromium steels is increased by phosphorus, manganese, and carbon, phosphorus having the strongest effect and carbon the smallest. In general, the Brinell hardness before and after embrittling treatment either remains the same, or may even be lower in the latter case.—R. A. R.

Galling Tests of Graphitic and Regular Oil-Hardening Die Steels. A. F. Sprankle and R. W. Dayton. (Metal Progress, 1948, vol. 54, July, pp. 65–69). Tests carried out on an Amsler wear-testing machine showed that, under test conditions simulating as far as possible cold-forming die operations, Graph-Mo steel required approximately twice the load to gall against a soft steel (S.A.E. 1015 of Brinell 90) as a conventional type of die steel. Since the hardness and other structural conditions of the materials were for all practical purposes the same, it is believed that this difference in galling resistance is attributable to the presence of graphite. The exact mechanism by which this improvement takes place is not understood, but may be associated with a number of hypotheses which are enumerated.—R. E.

Metallurgical Aspects of Ball Bearing Steels. A. S. Jameson. (Iron Age, 1948, vol. 162, Sept. 2, pp. 72–79; Sept. 9, pp. 81–87; Sept. 16, pp. 88–92). The first part of this article discusses the requirements of steels for ball bearings, the relation between chemical analysis and hardenability, and the effects of non-metallic inclusions and carbide segregation. The substitution of molybdenum for chromium is suggested. The second part presents hardenability data for the generally accepted combinations as well as for the author's new suggestions. Among relations discussed are those between austenitizing temperature and grain-size and between impact strength and grain-size. In the third part accelerated life test curves for a number of ball bearings of various steels are presented and the influence of molybdenum in increasing life is shown.—J. P. S.

New Die Steel Hardens by Precipitation. (Toolmaker, 1948, vol. 2, Jan., pp. 21–24 : Z.D.A. Abstracts, 1948, vol. 6, July, p. 99). To avoid the risks and expenses of heat-treatment, annealed alloy steels are often used for long runs, sometimes with hardened cavity inserts. The disadvantages of using soft dies are indicated, and the properties of a new steel, which is precipitation-hardened at 510° C., are described. PH No. 2 steel made by the Crucible Steel Co. of America has a Brinell hardness of 212 to 230 when fully annealed, and 260 to 290 when pretreated. In either state it is easily machined, and can be hardened to about 340 Brinell, in which condition machining is also said to be possible. Tests have been made over two years, and half a million heavy shots of zinc alloy have caused no signs of checking or erosion. Further erosion resistance can be obtained by nitriding.

Application of Statistical Methods to Study of Gas-Turbine Blade Failures. C. A. Hoffmann and G. M. Ault. (National Advisory Committee for Aeronautics, 1948, Technical Note No. 1603 : [Abstract] Metals Review, 1948, vol. 21, Aug., p. 30). This is a report of an investigation to determine applicability of statistical methods as an approach to the evaluation of materials when formed into a particular service shape and operated at accelerated life conditions.

Low-Alloy Steels. F. J. Erroll. (Automobile Engineer, 1948, vol. 38, Aug., pp. 289–290). Brief reference is made to some new low-alloy high-tensile steels made in the U.S.A., including Hi-Steel, Corten, Yoloy, Mayari, and Nax which are being used to an increasing extent in the automobile industry to save weight.—R. A. R.

Some Effects of Melting Practice on Properties of Medium-Carbon Low-Alloy Cast Steel. J. G. Kura and N. H. Keyser. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 119–133). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 307.

Occurrence of Intergranular Fracture in Cast Steels. C. H. Lorig and A. R. Elsea. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 160–174). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 301.

Gray Cast Iron. T. E. Barlow and C. H. Lorig. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 545–552). The authors discuss the relationships between the tensile strength, Brinell hardness, and composition of grey cast iron, and point out the need for a simple method of correlating and interpreting these properties to permit of accurate applications in engineering design.—R. E.

Gray Cast Iron Section Size *versus* Physical Properties. V. A. Crosby. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 791–794). This is a review of the work of a number of investigators on the effect of mass on the properties of grey cast iron. Twelve references to literature on the subject are appended.—R. E.

Unappreciated Advantages of Modern Gray Iron. F. G. Sefing. (Mechanical Engineering, 1948, vol. 70, Aug., pp. 667–670, 674). The author first outlines the range of properties of modern grey iron and then discusses its engineering applications. These include crankshafts because of its high vibration-damping capacity, high notch-fatigue strength, good wear properties on the bearings, and low cost of founding and machining as compared with rolling and machining; purposes where corrosion- and wear-resistance are important; and certain heavy-duty uses such as gears and machine-tool castings. The limitations on the use of grey iron are stressed.—J. C. R.

General Considerations on the Results of Tests Carried Out on Material from Iron and Steel Bridges Dynamited in 1940. J. Servais. (Bulletin de la Société Royale Belge des Ingénieurs et des Industriels, 1948, Série A, No. 3, pp. 160–179). A detailed account is given of tests carried out on specimens taken from an iron bridge built in 1868 and a steel bridge built in 1933. The tests included macrographic examination by the Baumann method; chemical analysis; tensile, bend, drop, and repeated impact tests; and micrographic examination. Specimens were also taken from other dynamited bridges and submitted to the same tests. The results are summarized and discussed.—J. C. R.

A Laboratory Evaluation of Some Automotive Cast Irons. A. B. Shuck. (American Foundrymen's Association, 1948, Preprint No. 48-11). Cupola-melted cast irons were examined to evaluate the effect of composition and cross-section on the mechanical and thermal properties, wear resistance, and microstructure. Test bars, varying in cross-section from $\frac{1}{4} \times \frac{1}{4}$ in. to $1\frac{1}{2} \times 1\frac{1}{2}$ in. were cast in green sand for each of the irons investigated. These were unalloyed, nickel–chromium, nickel–molybdenum, chromium–molybdenum, molybdenum, and nickel–molybdenum–chromium irons. Several carbon–silicon base compositions were melted in each type of alloy to determine the effects of carbon and silicon. It was found that the tensile strength increases with the refinement of the matrix and graphite structure produced by a decrease in cross-section. Low tensile strength may accompany very fine graphite when it is in the interdendritic form. Hardness increases with decreasing cross-section. The elastic modulus increases somewhat in the smaller cross-sections with the refinement of the graphite and matrix structures. Wear is influenced by microstructure and indirectly by casting cross-section. The nickel–chromium iron could be cast in a greater range of cross-section with a uniform pearlitic matrix structure than any of the other irons tested.

The Role of Vanadium in Gray Iron Castings. II. R. G. McElwee. (Vancoram Review, 1947, vol. 5, No. 2, pp. 14–16).

Vanadium Data Sheet. Vanadium Spring Steels. T. W. Merrill. (Vancoram Review, 1947, vol. 5, No. 2, pp. 12–13, 18 : Chemical Abstracts, 1948, vol. 42, Aug. 10, col. 5395). Tables give data on the analysis, treatment, properties, and uses of various vanadium steels.

METALLOGRAPHY

The Metallurgical Microscope. C. S. Middleton. (Proceedings of the Institute of Australian Foundrymen, 1942–43, vol. 3, pp. 179–186). The advantages and disadvantages of the arc lamp, pointolite, ribbon filament, and motor-car headlamp as light source for the microscope are discussed. For general work the D.C. pointolite is probably the best. The metallurgical microscope and the function of its parts are described. R. A. R.

The Application and Use of the Microscope. K. Winsor. (Proceedings of the Australian Institute of Foundrymen, 1942–43, vol. 3, pp. 213–231). After summarizing the history of the development of the microscope, the author shows its usefulness as an aid to control and to progress in the metallurgical field.—R. A. R.

Experimental Electron Microscope. (Engineer, 1948, vol. 185, May 28, p. 517). **50-kV. Electron Microscope.** (Engineering, 1948, vol. 166, Aug. 13, pp. 152–153). An experimental electron microscope designed and constructed by the Plessey Company, Ltd., is described. Suitable specimens can be directly viewed at magnifications up to 20,000 diameters, and the images can be directly enlarged by a factor of ten.—R. A. R.

Chromatic Aberration and Resolving Power in Electron Microscopy. E. G. Ramberg and J. Hillier. (Journal of Applied Physics, 1948, vol. 19, July, pp. 678–682). Contrast difficulties in the observation of fine detail in thin specimens may be overcome by employing dark-field observation. This introduces the added complication, however, that the imaging electrons are now inhomogeneous, having experienced a most probable energy loss of the order of 20 V. The present calculations of the effect of chromatic aberration and diffraction show that with an objective aperture smaller than the 'optimum aperture,' and centred optics, such inhomogeneities do not appreciably affect the resolution, even in the extreme case that the electrons are uniformly distributed in energy.

Correlation of Optical and Electron Microscopy. J. S. Bryner. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2364 : Metals Technology, 1948, vol. 15, June). In the study of metallographic specimens in the electron microscope the need arises for a method of locating the same field as has been studied in the light microscope. A method is described in which a special specimen screen, containing an opening which can be absolutely identified and quickly located in the electron microscope, is fastened to the silica-film replica in such a position that the desired field on the specimen would be located at the identifiable opening in the specimen screen.—R. A. R.

Micro-Radiography of Gray Cast Iron. E. I. Salkovitz, J. H. Schaum and F. W. von Batchelder. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 82–88). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 312.

Microstructure of Silvery Pig Iron. R. Schneidewind and C. Harmon. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 602–606). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 313.

Microstructure Related to Properties of Cast Iron. W. E. Mahin and H. W. Lownie, jun. (Transactions of the American Foundrymen's Association, 1946, vol. 54, pp. 294–302). *See* Journ. I. and S.I., 1946, No. I, p. 84A.

Structural Metallography of Iron–Carbon Castings. G. Testero and B. Parigi. (Ingegnere, 1948, vol. 22, pp. 89–95). This is a metallographic study of plain and alloy-iron castings after varying heat-treatments.

Etching of Microspecimens by Heating. A. Ts. Spektor. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 630–631 : Chemical Abstracts, 1948, vol. 42, Aug. 10, col. 5391). Place the specimen with polished surface up, on a metal sheet resting on an electric plate and heat. Observe the changes in coloration of the polished surface during heating. The dark blue colour which appears changes to grey, and then the surface becomes bright, as before the heating. At the instant when the grey colour changes to bright, immerse the specimen in water or mercury, taking care not to wet the polished surface. After cooling, the specimen is ready for examination. The cementite appears dark on a grey background of ferrite. This method can be used to determine the distribution and form of cementite in instrument steel during rolling and annealing.

Thermal Etching of Metals. R. Shuttleworth. (Metallurgia, 1948, vol. 38, July, pp. 125–131). Observations relating to grooves which develop when polished metal specimens of iron and steel, copper, tungsten, tantalum, and silver are maintained at a high temperature, are reviewed. Theories already advanced on the formation of boundary grooves and striations are discussed.—P. W.

Description of an Anodic Grip Used in Electrolytic Polishing. A. Lamare. (Métaux, Corrosion, Usure, 1945, vol. 20, June, pp. 83–84). In this appliance the arm is made of an acid-resisting plastic (styrolene) through which is passed a copper wire which is attached to a platinum disc. The specimen is held in position against the disc by the point of the plastic grip. The appliance is described and illustrated. It is claimed that all the disadvantages attaching to ordinary methods of electrolytic polishing are avoided and in addition the specimen is entirely immersed in the bath while the plastic grip can be rapidly and easily manipulated.—J. C. R.

Electrolytic Polishing of Steel. L. P. Zaytseva and L. Ya. Popilov. (Zavodskaya Laboratoriya, 1946, No. 7–8, pp. 679–692 : [Abstract] Electroplating, 1948, vol. 1, Aug., pp. 528, 530–531).

Contribution to the Study of Methods of Electrolytic Polishing of Metals. R. Piontelli, D. Porta, and L. Arduini. (Metallurgia Italiana, 1947, vol. 39, Jan.–Feb., pp. 15–23 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 7, p. 1220).

A Method for Determining the Origin of Surface Defects in Rolled Steel Products. C. L. Meyette and V. E. Elliott. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2368 : Metals Technology, 1948, vol. 15, June). A study was made of the diffusion of oxygen from oxide particles in defects occurring in the ingot stage and in defects arising during rolling. Holes were drilled 1 in. deep, packed with finely ground millscale, sealed by welding, heated for 1 hr. at 2150° F., cooled in air, and then sectioned and examined. Considerable diffusion occurred in all grades of steel except stainless steel, the oxide appearing as a band of fine precipitate parallel to the edge of the exposed surface.

Flaws were purposely produced by driving a cutter $\frac{1}{8}$-in. into cold and heated samples from billets ; the samples were reduced 50–80% in a small mill. Sections cut across the notch were examined at 400 diameters. Penetration of the oxide was present in both cases, but those notched in the hot state showed very much greater penetration. If a defect in rolled steel can be sectioned and examined, the extent of the diffusion of oxygen will indicate whether it originated before or during rolling.—R. A. R.

Segregation in Small Steel Castings. H. F. Bishop and K. E. Fritz. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 412–429). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 143.

Indicating the Carbides in Austenitic Chromium–Manganese Steels. W. Hofmann and R. Deponte. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 73–78). Metallographic and X-ray investigations were made on steels with up to 1·6% of carbon, 2% to 20% of manganese, and 15% of chromium. The carbides in the higher carbon alloys were isolated by dissolving the matrix and the existence of cubic and trigonal chromium carbide was confirmed. Trigonal chromium carbide in a needle-like form was also found in high carbon ferrochromium. Both forms of carbide have a high solubility for iron and chromium and their compositions are as given by A. Westgren, *i.e.*, $(Cr, Fe, Mn)_{23}C_6$ and $(Cr, Fe, Mn)_7C_3$.—R. A. R.

Determination of the Boundaries of Structural Elements in Metallographic Analysis. S. A. Saltykov. (Zavodskaya Laboratoriya, 1946, vol. 12, No. 1, pp. 79–89 : [Abstract] Revue de Métallurgie, 1948, vol. 45, Extraits, Mar.–Apr., p. 48).

Graphite Phase in Gray Cast Iron. R. W. Lindsay. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 134–159). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 293.

Isothermal Transformation of Molybdenum Cast Iron. C. Nagler and R. L. Dowdell. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 260–276). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 155.

Effect of Elements on the Polymorphism of Iron. W. Oelsen and F. Wever. (Kaiser-Wilhelm-Institut für Eisenforschung : Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 97–104). The formal application of thermodynamic relationships to the transformation equilibria of iron-rich alloys, and the use of small temperature changes caused by the transition of the alloying elements from the α- to the γ-phase as a measure for the nature and position of the transformation equilibria of these alloys are discussed.—R. A. R.

Dilatometric Investigations of Austenite Precipitation in the Intermediate Stage in Steels Low in Strategic Elements, and Their Mechanical Properties after Isothermal Heat-Treatment. A. Pomp and E. Rolf. (Kaiser-Wilhelm-Institut für Eisenforschung : Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 197–202). An apparatus is described with which the transformation of austenite during isothermal heat-treatment could be followed. The procedure was applied to two low-alloy steels (*A* C 0·34%, Mn 1·80%, Cr 0·22%, and *B* C 0·47%, Mn 0·72%, Cr 0·95%, V 0·12%) and their microstructures were examined. The effects of the initial hardening temperature, the intermediate bath temperatures and holding time were determined. Tensile strengths of 132 and 123 kg./sq. mm. were obtained for steels *A* and *B* respectively, with good elastic properties and better impact resistance than after ordinary heat-treatment. Bars up to 13 mm. in dia. could be heat-treated to strengths exceeding 125 kg./sq. mm.—A. R. R.

The Decomposition of Austenite by Nucleation and Growth Processes. R. F. Mehl. (Hatfield Memorial Lecture : Journal of The Iron and Steel Institute, 1948, vol. 159, June, pp. 113–129).

Cobalt and Iron. (Metal Industry, 1948, vol. 72, June 11, pp. 481, 487 ; June 25, pp. 524, 527). Published literature on thermal transformation in cobalt is reviewed.

The System Iron–Iron Sulfide (FeS)–Wustite (FeO). R. Vogel and W. Fülling. (Festskrift J. Arvid Hedvall, 1948, pp. 597–610 [in German] : Chemical Abstracts, 1948, vol. 42, Aug. 20, col. 5751). Phase diagrams were obtained for the FeS–FeO, Fe–FeS–Fe_3O_4, and Fe–FeS–FeO systems. In the FeS–FeO investigation mixtures of reduced iron, Fe_2O_3, and sulphur were melted in an argon atmosphere. A simple eutectic was observed at 920° and approximately 30% FeS. A mixture of FeS–FeO was stable from 920° to 570°, at which temperature a mixture of FeS–Fe_3O_4–α-Fe was obtained. Microscopic investigation suggested immiscibility of FeO and FeS in the solid state. Photographs were given of 88% FeS–12% FeO, 70% FeS–30% FeO, and 50% FeS–50% FeO. In the Fe–FeS–FeO system two immiscible liquids were formed with a critical point at 55% FeS, 40% Fe, and 5% FeO at a temperature of approximately 1320°. The branches of the miscibility curve ran near the Fe–FeS and FeS–FeO boundaries. Some sections of the diagram were given in detail. Photographs of the following compositions were presented, discussed, and the constituents identified : 58% FeS–32% FeO–10% Fe ; 28% FeS–35% FeO–37% Fe ; 42% FeS–50% FeO–8% Fe ; and 44% FeS–33% FeO–23% Fe.

An Interpretation of the Constitution of Iron–Carbon–Silicon Alloys. J. E. Rehder. (Transactions of the American Foundrymen's Association, 1947, vol. 55, pp. 71–81). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 155.

The Iron–Sulphur–Titanium Constitutional Diagram. R. Vogel and G-W. Kasten. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 65–71). The Fe–FeS–TiS–Fe_2Ti part of the iron–sulphur–titanium system was thermally and microscopically investigated and the constitutional diagram constructed. A miscibility gap in the liquid state extends from the boundary system Fe_2Ti–FeS deep into the iron corner of the concentration quadrilateral and approaches the boundary within less than 1% titanium. Thus titanium is one of the elements which, when a small quantity is added to a melt of iron and iron sulphide, will cause immiscibility. The equilibrium line runs from Fe to TiS. Titanium thus converts FeS into TiS and there would be no FeS structural constituent present when the titanium content is below the equilibrium line ; instead there would be TiS or a solid solution of TiS and FeS.—R. A. R.

CORROSION

Electrochemistry of Corrosion Phenomena. I—Importance of the Characteristics of Local Cells in an Acidic Medium. L. Cavallaro and A. Indelli. (Ricero Scientifica e Ricostruzione, 1947, vol. 17, pp. 939–941 : British Abstracts BI, 1948, July, col. 327). Experimental results tabulated for soft steel, 13% Cr steel, and 18/8 acid-resisting steel show the anode and cathode potentials (referred to a saturated calomel electrode in a polarizing field of 2 V.), the corresponding current, the 'mixed potentials' resulting in a closed circuit but without the polarizing field, and the current corresponding with the local electrochemical corrosion cell. The results may be used to determine the slopes of the polarization curves (by Evans' method), and to demonstrate whether a corrosion reaction is predominantly anodic or cathodic in type. In the present instance the increasing predominance of the anodic reaction with increasing corrosion resistance of the steel samples studied is demonstrated.

Corrosion Prevention in Processing Sour Crudes. E. Q. Camp. (Corrosion, 1948, vol. 4, Aug., pp. 371–398). Some of the major corrosion problems experienced in processing sour crudes (high-sulphur crude oil) and methods employed to mitigate these corrosion problems are discussed. The corrosion problems dealt with include hydrogen sulphide, dissolved oxygen, carbon dioxide, and high temperature corrosion. Various methods of increasing the life of steel tanks, and methods used for the protection of various refinery equipment (*i.e.*, lines, furnace tubes, condensers, cracking units, etc.) are discussed in detail. The results of laboratory tests to study the corrosion effect of 'Refugio Naphta' on stainless steel are given. A bibliography of 29 references is appended.—R. F. F.

Corrosion in Vertical Turbine Pumps. T. E. Larson. (Corrosion, 1948, vol. 4, Aug., pp. 412–420). Galvanic action, water-line corrosion, carbon dioxide corrosion, and corrosion caused by stray currents, which are the forms of corrosion affecting pumps, are discussed. The various means of protecting pumps and column pipes are briefly described.—R. F. F.

Corrosion Phenomena of Underground Piping. A. J. Maurin. (Energie, 1948, vol. 32, Sept., pp. 193–199). Electrogalvanic corrosion of steel pipe lines is discussed. Methods of measuring the current in the pipes, of discovering the origin of the current and of determining the type of corrosion prevalent are given. Methods of protection are suggested.—R. F. F.

Inhibiting Corrosion in Packaged Goods. (Electroplating, 1948, vol. 1, Aug., pp. 533–534). A new method for the prevention of corrosion in packaged goods is described, in which a volatile benzoate is introduced inside the wrapping. The inhibitors are also effective in preventing corrosion under conditions of supersaturation with water vapour and temperatures of 50° C. The benzoate may be impregnated in the wrapping material, loose packing or in absorbent material suspended in the container.—J. C. R.

Electrochemical Study of Corrosion of Metals in Ethylene Glycol Solutions. N. D. Tomashov and M. A. Timanova. (Journal of Physical Chemistry (U.S.S.R.), 1948, vol. 22, pp. 221–231 [in Russian]: Chemical Abstracts, 1948, vol. 42, July 20, col. 4894). Cathodic polarization of copper and iron in 55% aqueous glycol is determined by depolarization by dissolved oxygen. The limiting c.d. is at 16° 0·005 m.amp./sq. cm. for both metals. The cathodic polarization of aluminium is complicated by solution of the oxide film. Addition of water lowers the hydrogen overvoltage and raises i_0; in pure water, i_0 = 0·015 m.amp./sq. cm. Anodic polarizibility of copper, iron, and aluminium is very small. Calculation of the potential drop in the local cells shows that corrosion in aqueous glycol is determined mainly by the cathodic polarization, the ohmic drop of potential being negligible except when the dissimilar metals are separated by several cm. This is important for corrosion by antifreeze solutions. The corrosion inhibitor V-2 containing dextrin and phosphate (no exact composition given) little affects the cathodic polarization of copper, iron, and aluminium in 55% glycol, but raises the anodic polarization, *e.g.*, from 0·2 to 1·5 V. Phosphate seems to be the active ingredient of the inhibitor. In the presence of inhibitor, corrosion is determined by the anodic process.

Corrosion by Molten Materials. F. R. Morral. (Wire and Wire Products, 1948, vol. 23, June, pp. 484–489; July, pp. 571–579). Data are presented in three long tables on the corrosion by molten substances of materials used for the construction of containers. In Table I the corroding agents are elements, chiefly metals; in Table II they are molten salts; and in Table III mixtures of molten salts. Each item has one or more references numbers which link it to the extensive bibliography.—R. A. R.

The Structure of Oxide Layers and the Mechanism of the Oxidation of Steel at High Temperatures. V. I. Arkharov. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Techniques, 1946, No. 1, pp. 127–132; No. 3, pp. 453–458).

ANALYSIS

The Determination of Impurities in Metals. H. A. Nipper. (Gjuteriet, 1948, vol. 38, Sept., pp. 129–134). [In Swedish]. Direct and indirect methods of determining the composition and distribution of non-metallic inclusions in metals are described, including the chlorine, bromine, and iodine methods of dissolving the metals and the Skapski and Benedicks procedure for treating a very thin section of steel on quartz with chlorine and hydrochloric acid so as to remove the iron and leave the inclusions in their original positions.—R. A. R.

The Duration of Analysis in Chemical Laboratories. A. G. Bogdanchenko. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 749–750). [In Russian]. A number of analytical operations used in ferrous metallurgical laboratories are tabulated, together with the weights of sample required and the average and minimum times necessary for their execution. S. K.

Apparatus for Measuring the Surface Tension of Liquid Metals. L. L. Kunin and Yu. A. Klyachko. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 756–758). [In Russian]. A description is given of an apparatus in which the surface tension of molten metals or the tension at the metal-slag interface can be measured in a controlled atmosphere.—S. K.

Practical Application of Spectrum Analysis to Iron and Steel. S. Kobayashi. (Journal of the Society of Chemical Industry, Japan, 1943, vol. 46, pp. 244–247: Chemical Abstracts, 1948, vol. 42, Sept. 10, col. 6266). In the analysis of iron and steel, an element having an atomic number greatly different from that of iron is likely to cause deviations due to the shape of the electrodes and the conditions of electric discharge. Some elements, especially molybdenum, are likely to excite or suppress the lines of other co-existent elements. The method is useful for determining the quality of material during the working, and to study the composition of molten steel.

Spectrochemical Analysis. F. Twyman. (Research, 1948, vol. 1, June, pp. 388–393). The fundamental principles of optical, infra-red, and X-ray spectrography are described; in reference to the metallurgical applications of optical spectrographic analysis, the author refers to the use of external standards and the homologous line-pairs and to special techniques employing photocells for the rapid determination of a predetermined number of elements.—J. P. S.

The Electrical Apparatus for Exciting Spectra in Qualitative and Quantitative Spectrum Analysis. O. Werner. (Metallwirtschaft, 1948, Mar., pp. 69–74; Apr., pp. 114–117). High-tension spark, low-tension arc and low-tension spark methods of exciting spectra for spectrum analysis are reviewed. A great variety of methods is available, but for routine work the choice can be considerably reduced. The high-tension spark and the electrically ignited intermittent arc have reached the state of development where some standardization of apparatus with a reduction in cost could be introduced, which would also make it easier to train operators.—R. A. R.

Improvements to the Hilger Non-Recording Photoelectric Microphotometer. (Instrument Practice, 1948, vol. 2, Aug., p. 414). The improvements described can be fitted to any recent standard Hilger microphotometer. They include a device for rapidly aligning a desired part of a spectrum with the slit on the photocell housing used for measurement. Another device is the Hilger Galvoscale Projector for facilitating making galvanometer readings.—R. A. R.

Correction for Gamma Changes Due to Variations in Exposure and Development with Reference to Spectrographic Analysis (Two Line-Pair Method). C. Sanders. (British Iron and Steel Research Association: Journal of the Society of Chemical Industry, 1948, vol. 67, May, pp. 185–187). The procedure described has been found useful in the spectrographic determination of composition by the method in which the log. ratio of deflection is plotted against percentage content (or log. percentage content), no intensity calibration being carried out. Essentially the procedure consists of using two line-pairs for each determination, one on the positive and the other on the negative side of log. ratio 0·000. Where the log. ratio is reasonably near zero it is, of course, unnecessary to read two line-pairs. By placing a straight edge through the log. ratio points on the corresponding composition curves and reading off the composition corresponding to the log. ratio 0·000 on this straight line, a weighted average is obtained which corrects for plate response, thus giving a better accuracy than that obtained by the use of individual line-pairs and log. ratios uncorrected for intensity by plate characteristic curve technique.

A New Method of Photographic Evaluation in Spectrographic Analysis. A. Argyle and W. J. Price. (British Iron and Steel Research Association: Journal of the Society of Chemical Industry, 1948, vol. 67, May, pp. 187–190). A simple nomographical method of evaluation of minor constituents is given which, provided that the density values all fall on the straight line portion of the H and D curve of the emulsion used, is independent of gamma variation. When the nomograph is drawn, not only does it correct for changes in gamma across one plate, but also from plate to plate of any type, thus obviating the need for repeated standardization.

Spectroscopic Determination of Carbon in Iron and Steel. O. V. Blank and N. S. Sventitsky. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1945, vol. 45, No. 4, pp. 252–255). In the visible spectrum a broad carbon line results from the overlapping of two spark lines at 4267 Å. By using a large capacitance and spark gap only 0·8 mm. long with a powerful transformer, this line can be recorded in spectra of steels with carbon 0·3% to 4%. The density contour of the diffuse CII line is plotted, and its area is measured and compared with the blackening of the spectrum at wavelength 4270. When these relative densities are plotted against the percentage of carbon, the points for steel and cast iron fall on a single straight line.

In the ultra-violet region the line CIII 2296·92 is used, and compared with the line Fe 2294·6 in the range 0·1% to 4% of carbon. A background correction is necessary if nickel is present above 1%. Steel and cast iron were combined to give a single calibration line.—E. VAN S.

Spectrographic Estimation of Traces of Boron in Steel by Means of a Medium Dispersion Spectrograph. J. M. Pheline and R. Castro. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 9th Congress, 27–29 Jan., 1948, pp. 35–42). An A.C. arc maintained by high-frequency discharge using only 2 amp. is used to record steel spectra on a spectrograph of such dispersion that the whole spectrum is on a plate 24 cm. long. A recording microphotometer (Moll) is used to trace the contour of certain spectrum lines, of boron and iron, which

are then evaluated by the method of Coheur in which the width of the iron line is measured at the density level corresponding to the peak of the boron line. National Bureau of Standards steel samples are used to calibrate this method in the range of 0·0006% to 0·019% boron, and at intermediate contents a precision of 3% is obtained. A bibliography which also covers chemical methods of estimating boron is appended. E. VAN S.

Results of the Analysis of Steel Obtained with the A.R.L. Equipment. P. Coheur and A. Hans. (Groupement pour l'Avancement des Méthodes Spectrographique des Produits Métallurgiques, 9th Congress, 27–29 Jan., 1948, pp. 43–48). A controlled spark source and grating spectrograph from the U.S. suppliers (Applied Research Laboratories) has been applied to the estimation of nickel, chromium, manganese, silicon, molybdenum, copper, and tin in alloy steels. Calibration of the films used was by means of 14 iron lines, whose relative intensities were known from previous measurements, and these data are tabulated. Flat surface steel samples were sparked with graphite counter-electrodes and one set of electric parameters was suitable for all these elements except tin. For the concentration of about 0·01% of tin, larger capacitance and inductance were chosen so as to give a more arc-like discharge. Index points for several line-pairs are given for each of the elements estimated, and the accuracy was of the order of 3% for the first photographic materials used, and was improved to about 1·5% by changing the photographic technique. These figures are for the standard deviation of 20 spectra.—E. VAN S.

On the Accuracy of the Results of Chemical Analysis of Steels. G. Brucelle. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 9th Congress, 27–29 Jan., 1948, pp. 55–57). While collecting standard analysed samples for use as spectrographic standards the Central Armaments Laboratory in Paris compared the results of their own tests with those of seven other laboratories on 39 samples of steel. The proportion of the results for which the estimates for the same element differed by more than 20% in the laboratories ranged from 5% for manganese to 50% for vanadium. The order of increasing uncertainty for the elements tested was manganese, chromium, nickel, tungsten, molybdenum, silicon, and vanadium; but the number of tests for vanadium and tungsten is too small to be significant. The figures are only given to show the need for further investigation; but the author remarks on the illusory nature of the fourth significant figure occasionaly written down by analysts.—E. VAN S.

Present Stage and Standardisation of Spectrographic Methods at the Klus Works (Switzerland). C. Burkhardt. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 9th Congress, 27–29 Jan., 1948, pp. 59–64). Spark spectra and a medium quartz spectrograph are applied to routine quality control of bearing metals, bronzes, and high-alloy steels. A controlled spark is used, with different discharge conditions for each type of alloy; all exposures are made through a step-wedge which records the spectrum at three levels of density. This provides an extremely simple method of plate calibration at every wavelength used, which makes it unnecessary to repeat standard sample spectra on the routine plates. The wavelengths used are tabulated for cobalt, tungsten, vanadium, molybdenum, manganese, and titanium in steel, as well as for chromium in the range 8–15%. Except for silicon and titanium, satisfacory precision is obtained. The usual minor constituents in bronzes and light metals are estimated, and antimony, tin, copper, and arsenic in lead-base bearing metals.—E. VAN S.

Spectrographic Techniques and Rapid Methods of Calculation. Jean. (Groupement pour l'Avancement des Méthodes Spectrographique des Produits Métallurgiques, 9th Congress, 27–29 Jan., 1948, pp. 89–108). A detailed summary of most of the known methods of working out results in spectrochemical analysis is given, with a bibliography of the principal publications in the U.S.A., Great Britain, and France. The method selected makes use of no new principle, but is chosen for its simplicity and rapidity. Plate calibration by measurement of selected lines of the iron spectrum is followed by analysis based on a set of calibration lines calculated from index points, using a single double logarithmic plot for all the lines, and a movable logarithmic scale. Experiments show that this method is independent of plate contrast factors, and that the effect of the latter on the precision of analysis has been exaggerated. Previously published (6th Congress) data for impurities in steel are used to illustrate the method.—E. VAN S.

Spectrographic Analysis of Steel with a Counter-Electrode. C. Burkhardt. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 9th Congress, 27–29 Jan., 1948, pp. 115–120). For routine analysis of stainless steel, and other highly alloyed steels, a spark between a flat surface and an aluminium counter-electrode is more convenient than one between a pair of electrodes which have to be machined from the sample. Iron as a counter-electrode gives poorer reproducibility. An arc-like spark is secured by raising the self-inductance to 0·8 mH, and increasing the energy of the spark with extra capacitance. Suitable line-pairs are tabulated for chromium, cobalt, tungsten, molybdenum, silicon, manganese, titanium, and vanadium; a spectrograph of inadequate dispersion is used and microphotometric traces of some of the spectral regions are used to detect interfering lines. An adaptation of a background-correction method to provide a quantitative correction for an interfering line is described. Statistical tests show the precision to be similar to that of routine chemical analysis, or slightly better, except in the case of silicon where no suitable spectrum line was available.—E. VAN S.

Sample Electrode Vapour Contamination of the Graphite Electrode in the Flat Surface Sparking Technique of Spectrochemical Analysis. D. M. de Waal and S. M. Naude. (Spectrochimica Acta, 1948, vol. 3, No. 2, pp. 127–140). In the analysis of steel by sparking a flat surface of the sample against a graphite counter-electrode the variation of the spectrum has been explored both in space and in time. Important changes in the radiation result from heating of the sample and from condensation of the metal vapour on the graphite electrode, these are described in terms of iron spark to iron arc lines, and by rotating-mirror photographs. The best shape for the point of the graphite electrode is found to be a cone with an included angle of 80° rather than a smaller angle.—E. VAN S.

An Investigation of Spectrochemical Sparking-Off Effects in the Flat Surface Sparking of Steels. D. M. de Waal and A. Strasheim. (Spectrochimica Acta, 1948, vol. 3, No. 2, pp. 141–158). The effect of using two steel electrodes, one steel rod and one carbon, and one steel surface against carbon on the uniformity of the spectrum in time is examined, and also the variation of the radiation at different parts of the spark. A spark gap only 1·5 mm. long is recommended to minimize variability of the spark in respect of the relative intensity of chromium, manganese, and nickel lines compared with iron lines. The effect of oxidation, and of atmospheric humidity is shown to be variable for different elements, and changes of humidity are suggested as one of the causes of drift in calibration curves.—E. VAN S.

The Statistical Treatment of the Results of Analyses of Standard Samples. A. V. Groshev and V. I. Ponosov. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 669–677). [In Russian]. The statistical treatment of analytical results is discussed and illustrated by reference to determinations of manganese in steel made by the bismuthate and persulphate methods, respectively.—S. K.

A Contribution to the Question of the Experimental Bases of the Method of Taking and Preparing Laboratory Samples for Analysis. T. G. Fomenko, and N. V. Baryshev. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 678–686). [In Russian]. The first part consists of some criticisms by Fomenko of an article by Baryshev (Zavodskaya Laboratoriya, 1947, vol. 13, May) on the experimental procedure for taking and preparing samples for analysis, with special reference to sizing and amount of sample; the second and longer part contains Baryshev's answers to these criticisms. S. K.

A Quick Method for the Determination of Sulphide Sulphur. Yu. A. Chernikhov and R. F. Makarova. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 649–653). [In Russian]. An account is given of the determination of pyritic sulphur by combustion and measurement of the sulphur dioxide produced, the influence of sulphates, lime, silica, and ferric oxide being considered.—S. K.

Determination of Inclusions of Iron and Manganese Sulphides in Weld Metal. E. E. Cheburkova. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 654–657). [In Russian]. A method for the determination of sulphide inclusions in weld metal based on anodic solution followed by the treatment of the residue with acetic acid, is described with particular reference to iron and manganese.—S. K.

The Turbidimetric Determination of Sulphur in Iron and Steel. G. Geuer. (Archiv für das Eisenhüttenwesen, 1948, vol. 19, pp. 25–27). In the procedure described the sulphurous gases obtained by combustion are passed into a lead acetate solution of suitable *p*H value, whereupon a milky-white cloud is formed, the density of which is measured photometrically. The determination takes about 5 min.—R. A. R.

Determination of Sulphur in Pure Iron. S. Kitahara. (Bulletin of the Institute of Physical and Chemical Research [Tokyo], 1947, vol. 23, pp. 659–668 : Chemical Abstracts, 1948, vol. 42, Aug. 10, col. 5376). A method of determining a minute amount of sulphur in iron, is discussed. The method consists in dissolving the sample in HNO_3 and $KClO_3$, converting the solution to an HCl solution, removing most of the $FeCl_3$ by extracting with ether saturated with HCl, reducing the remaining Fe^{+++} with zinc, and precipitating SO_4^{-2} as $BaSO_4$.

Electrometric Determination of Vanadium in Steels. A. Claassen and J. Corbey. (Recueil des Travaux Chimiques des Pays-Bas, 1948, vol. 67, pp. 5–10 : Chemical Abstracts 1948, vol. 42, July 20, col. 4867–4868).

The Isolation of the Carbide Phase under Constant Conditions. N. M. Popova and M. F. Rybina. (Zavodskaya Laboratoriya, 1948, vol. 14, May, pp. 555–557). [In Russian]. A description is given of a method by which the electrolytic separation of the carbide phase can be carried out under constant conditions. A special apparatus is used in which the steel specimen is in the form of a cylinder and is made the anode in a cooled, circulating electrolyte. The cylinder is rotated mechanically at 30–60 r.p.m., rubber-sprung glass brushes removing the carbide as it appears. The carbide phase falling from the anode is collected in a cooled vessel and subsequently analysed. During the process an atmosphere of hydrogen is maintained. Some examples of the application of the method are given.—S. K.

Determination of the Carbides of Chromium and Iron in Austenitic Chromium–Nickel Steels. N. M. Popova and A. F. Platonova. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 658–661). [In Russian]. The determination of iron and chromium carbides in austenitic chromium–nickel and chromium–manganese steels, based on the use of an acidic chloride electrolyte containing thiosulphate, is described.—S. K.

Rapid Spectrographic Analysis of Cemented Carbide Compositions. J. C. Redmond. (Steel, 1948, vol. 122, June 28, pp. 86, 88). A spectrographic technique for the rapid determination of cobalt, titanium, tantalum, tungsten, and niobium in cemented carbides is described. A Hilger large quartz prism and a 10μ slit are used, and it is necessary to grind the sample in a carbide mortar and pestle to particles about 1–2 microns in dia.—R. A. R.

Determination of Silicon in Silicon Spring Steel by the Use of a Steeloscope. G. P. Preobrazhenskaya. (Zavodskaya Laboratoriya, 1948, vol. 14, June, p. 759). [In Russian]. A brief account is given of the use of a steeloscope for the determination of silicon in spring steel, three lines of iron and one of silicon being employed. The comparative intensities of the lines for different concentrations of silicon from 1·1% to 2·0% are shown.—S. K.

Spectrum Analysis of Slags. N. V. Buyanov. (Zavodskaya Laboratoriya, 1948, vol. 14, May. pp. 565–570). [In Russian]. A detailed account is given of a method of spectrum analysis which was found to be satisfactory for complex slags. A 0·5-g. sample, crushed to 200 mesh, was evenly sprinkled along the longer side of a 90 × 45-mm. plate (the lower electrode of an arc gap) to form a strip 10–12 mm. wide and 85–90 mm. long. After a 1500-V. arc had been struck, the lower electrode was slowly moved with respect to the stationary upper electrode for 2 min., this being the exposure. Calibration curves were obtained from the spectra of 28 samples of low-chromium slags, the composition of which had been established chemically. Applied to the analysis of a slag containing the oxides of silicon, magnesium, manganese, chromium, calcium, aluminium, and iron, the method gave results varying by ± 1·5–5·0%, the time required for analysis for seven elements being 20–25 min.—S. K.

Determination of Volatile Components Using Diffusion of the Gases. R. S. Pilnik and A. A. Sycheva. (Zavodskaya Laboratoriya, 1948, vol. 14, June, pp. 710–713). [In Russian]. A description is given of the application of microchemical diffusion methods to the semi-micro determination of carbon dioxide, ammonia, and hydrogen sulphide. These determinations are carried out at room temperature and require very little attention while they are in progress.—S. K.

The Moisture in Industrial Gases. Part II.—Application of the Moisture Calculation. F. Lüth. (Iron and Steel Institute, 1948, Translation Series, No. 353). An English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1930–31, vol. 4, Oct., pp. 185–192 (*see* Journ. I. and S.I., 1930, No. II, p. 452).—R. A. R.

Losses through Using Hydrochloric Acid in the Determination of Nitrogen by the Solution Method. H. Kempf and K. Abresch. (Archiv für des Eisenhüttenwesen, 1948, vol. 19, pp. 17–19). It is shown that when determining nitrogen in ferromanganese (Mn 16–44%) some of the nitrogen does not form ammonia or ammonium chloride when the sample is dissolved in hydrochloric acid. If the sample is dissolved in dilute sulphuric acid there is no loss of nitrogen. There is a relation between the silicon content of ferromanganese and the amount of nitrogen not taken up. There is no nitrogen loss when 70–90% ferromanganese is dissolved in hydrochloric acid.—R. A. R.

Adsorption of Oxygen on Iron and Influence of Adsorbed Oxygen on the Behaviour of an Iron Electrode. R. Burstein, N. Shumilova and K. Golbert. (Acta Physicochimica, U.R.S.S., 1946, vol. 21, No. 5, pp. 785–802).

A New Method for Measuring Adsorption of Gases and Vapours by Solids. B. P. Bering and V. V. Sepinsky. (Comptes Rendus de l'Académie des Sciences, U.R.S.S., 1947, vol. 55, No. 8, pp. 731–734).

Determination of Hydrogen in Steel under Production Conditions. N. M. Chuiko. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 296–298 : Chemical Abstracts, 1948, vol. 42, July 10, col. 4492–4493). In sampling the metal from the arm of the modified Herty sampler there is a loss of hydrogen when more than 0·0015% is present ; this will take place despite the addition of aluminium. It is proposed to withdraw metal from the furnace into a sampler having a vacuum of less than 1 mm. Hg. The gases liberated during solidification of the steel are collected, and the sample is then used to determine the remaining hydrogen, The samples are clean and require no treatment and can be of any diameter from 8 to 15 mm, and of any desired length. The remaining hydrogen can be determined by the Newell method. A diagram of the sampler is shown.

The Sampling and Analysis of Steels for Hydrogen. G. Derge, W. Pfeifer, and J. H. Richards. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2362 : Metals Technology, 1948, vol. 15, June). A description is given of a vacuum-fusion apparatus for determining hydrogen in steel and of the modifications and precautions which were applied to reduce the probable error to ± 0·00001%. The behaviour of hydrogen in rail steel was then examined. The initial hydrogen content was about 0·0003% and this decreased to about 0·00003% in about 60 days, after which there was no observable change. If the gas which escapes in this period is considered as " diffusible hydrogen " and treated in accordance with the diffusion theory, it is possible to extend a limited number of analyses to cover the changes in hydrogen content of specimens of any size or shape at any temperature below the critical. Data taken from rail steels confirm that this can be done.—R. A. R.

Apparatus for the Hot-Extraction Analysis for Hydrogen in Steel. C. E. Sims and G. A. Moore. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2369 : Metals Technology, 1948, vol. 15, June). The construction and operation of apparatus developed at Battelle Memorial Institute for the quantitative extraction of hydrogen from steel in a high vacuum at temperatures up to 1050° C. are described.—R. A. R.

ECONOMICS AND STATISTICS

The British Iron and Steel Industry. A Review of Progress and Policy. (Metallurgia, 1948, vol. 38, July, pp. 137–143). Conditions existing in the British iron and steel industry in the period 1918–39 are reviewed and discussed. The

industry's service to the nation in the 1939–45 war is recalled, and a concise summary of new plant under construction and present research activities is followed by a brief discussion of the question of public ownership of the industry.—P. W.

Productivity in the Steel Industry. (British Iron and Steel Federation Monthly Statistical Bulletin, 1948, Aug., pp. 1–6). Methods of measuring the productivity of the steel industry are explained and data on the number of workers employed and their distribution, output per man-year, and wages and prices are given. Comparison between data for the U.S.A. and Great Britain is made.—R. A. R.

Productivity in the Steel Industry. (Records and Statistics, 1948, vol. 4, Oct. 2, pp. 312–313). Statistics on production and employment in the steel industry published by the British Iron and Steel Federation are discussed.—R. A. R.

The Iron and Steel Development Plan : Some Statistical Considerations. R. M. Shone. (Journal of the Royal Statistical Society, 1947, vol. 110, Part IV, pp. 283–309). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 478.

The Australian Iron and Steel Industry. (British Iron and Steel Federation Monthly Statistical Bulletin, 1948, vol. 23, July, pp. 5–14). A survey of the iron and steel industry of Australia is presented. The industry has two particularly striking features ; one is that, thanks to the raw material position, Australia is today probably the lowest-cost producer of iron and steel in the world ; secondly, owing to the shortage of labour, about 25% of the capacity of nearly 2,000,000 ingot tons per annum is not being used.—R. A. R.

Iron and Steel in Australia. Essington Lewis. (Australian Institute of Metals : Australasian Engineer, 1948, Apr.7, pp. 43–50). The author discusses the whole of the Australian iron and steel industry, from the native raw materials, their occurrence and exploitation, to the production of iron and steel in a variety of forms, and ferro-alloys. The allied industries of shipbuilding and general engineering are also covered, and the proposed establishment of a hot- and cold-strip mill and tinplate plant at Port Kembla is mentioned.
J. P. S.

The Iron and Steel Industry of India. F. Marle. (Génie Civil, 1948, vol. 125, Aug. 1, pp. 287–289). The iron and steel industry of India is surveyed and future prospects are outlined.
R. F. F.

The Iron and Steel Industry in Sweden. F. Marle. (Génie Civil, 1948, vol. 125, Sept. 15, pp. 349–351). The Swedish iron and steel industry is surveyed and future prospects are discussed.—R. F. F.

New Tendencies in the Swedish Iron and Steel Industry. (Economische Voorlichting : Österreichischer Maschinenmarkt und Eisenhandel, 1948, vol. 3, Apr., pp. 72–73). Economic aspects of the Swedish iron and steel industry are reviewed. The decrease in the consumption of charcoal, the increase in the production of sponge iron and the present position in the development of the State plant, Norbottens Jernwerk, near Luleå, are commented on.—R. A. R.

Prospects in Argentina. (British Iron and Steel Federation Monthly Statistical Bulletin, 1948, vol. 23, June, pp. 10–16). **Steel in Argentina.** (Iron and Coal Trades Review, 1948, vol. 157, July 16, pp. 139–140). The economic situation in the Argentine which led to the recent decision of the Argentine Government to establish a heavy industry in spite of the known unfavourable conditions is reviewed, and an attempt is made to forecast its effect on trade with the United Kingdom.—R. A. R.

Mexico's Steel Industry. C. E. Plumb. (Electrical Engineering, 1948, vol. 67, June, pp. 533–534). The present position and prospects of Mexico's steel industry are discussed. The output is fairly well controlled by six companies, the total production of which in 1946 was about 335,000 metric tons. The industry is based on indigenous iron ore and coking coal. One company can roll sections up to 12-in. girders and another company now rolls plates and sheets. Extensive plans for the development of the country ensure a large demand for iron and steel products for a long time to come.—R. A. R.

Sufficient Iron Ore ? (Economist, 1948, vol. 154, June 26, pp. 1074–1075). The shortage of rich iron ore and its effects are discussed. Germany has been supplied with dollars so that she can replace lean French ore by Swedish ore and thus counteract the lack of coke. Marshall Aid is then left to ease the financial strains resulting from this distortion of normal trade. Thus the confusion of intra-European trade which Marshall Aid is intended to resolve, seems in this case to be increased.

To improve the English position, more home ore, more scientifically prepared, may be the best and only answer to the problem in the short run, but it is unlikely to be the permanent answer. Resources in Rhodesia require exploiting, and those of Africa and Australia have still to be proved and recorded in full, and these may supply the long-term answer.
R. A. R.

MISCELLANEOUS

The Organization of Scientific Research in Great Britain. H. R. Mills. (British Science News, 1948, vol. 1, No. 8, pp. 2–10). This account of the way in which scientific research is organized in Great Britain covers the Government's Scientific research policy ; Government research through the laboratories of the Department of Scientific and Industrial Research ; medical and agricultural research ; the work of other Government Departments, universities, and the learned societies, Government expenditure on research ; liaison overseas ; and British Commonwealth scientific offices.—R. A. R.

The Unit Process of Chemical Metallurgy. R. Schuhmann, jun. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2363 : Metals Technology, 1948, vol. 15, June). The subdivision of industrial processes into unit operations of a physical nature and unit processes of a chemical nature is discussed. Tables of these units are presented, and the application of the unit-process approach to college curricula is explained.—R. A. R.

The Production of Oxygen. C. Danielsson. (Värmländska Bergsmannaföreningens Annaler, 1948, pp. 67–106). An outline is given of the methods by which oxygen gas is produced. Consideration is especially given to the most important method, *i.e.*, distillation of liquid air, and the author gives theoretical aspects as well as practical experience. In conjunction with this, data on the power requirements and efficiency in oxygen production are given. The costs of oxygen production at Swedish, French and American works are discussed. In conclusion mention is made of accident risks at oxygen plants and the production and transport of liquid oxygen. There are 44 references.—J. K.

Corrigenda

The following corrections to abstracts in the September *Journal* should be noted—Page 103, last abstract : the author's name should be F. Castagneri ; page 105, column 2, abstract 9 : first word should read " Variable " ; page 115, column 2, abstract 7 and page 116, column 2, abstract 5 : the authors' names should be J. M. Vialle and E. K. Zavoiskii, respectively.

The Preparation of Feed Water, with and without Phosphate, for Large Smoke-Tube Boilers. K. Griebel. (Stahl und Eisen, 1948, vol. 68, May 20, pp. 192–197).

Modern Methods of Feedwater Conditioning for High Pressure Boiler Plants. S. D. Distelhorst. (Iron and Steel Engineer, 1948, vol. 25, July, pp. 53–57). Equipment and processes for reducing the hardness, total solids, silica, and alkali content of water for high-pressure boilers are described with notes on single-stage, two-stage, and zeolite softeners.
R. A. R.

Hot-Process Conditioned Water for High-Pressure Boilers. A. C. Dresher. (Combustion, 1948, vol. 19, Jan., p. 31. [Abstract]. British Coal Utilisation Research Association, Monthly Bulletin, 1948, vol. 12, Apr., p. 143). Four requirements for satisfactory boiler feedwater are discussed : (1) " Zero-hardness," *i.e.*, reduction of hardness to a minimum. (Hard water is treated with lime and soda ash, followed by phosphate. Less than 50 p.p.m. hardness will require only phosphate and caustic soda as reagents). (2) Low total solids. (3) Low concentrations of silica. (4) Low alkalinity.

An Exact Method of Dispersion Analysis Using the Supercentrifuge. V. I. Sokolov. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 435–440). [In Russian]. Equations are developed for dispersion analysis, taking into account the variation in the speed of the different layers of the system in the supercentrifuge and the unequal speed of sedimentation of the particles.

BOOK NOTICES and NEW PUBLICATIONS

BOOK NOTICES

"*Die Energiebriefe des Dr. cal. Sparfleiss.*" 8vo, pp. 169. Düsseldorf, 1948: Verlag Stahleisen m.b.H. (Price 3.75 DM.).

The last edition of this small work appeared in 1943 and it has now been rearranged and brought up-to-date. It takes the form of a series of letters between a qualified fuel efficiency expert and a works' fuel watcher. These letters impart facts about fuel economy collected during the 30 years' active experience of the author, Professor Dr. Kurt Rummel. It is written in a clear manner to be understood by furnacemen and stokers and should be equally useful to foremen and managers of power plants. Information is included on the development of the steam turbine and the future development of gas turbines and atomic energy power stations.—R. E.

FOSTER, P. FIELD. "*The Mechanical Testing of Metals and Alloys.*" Fourth Edition. 8vo, pp. vii + 319. Illustrated. London, 1948: Sir Isaac Pitman and Sons, Ltd. (Price 18*s.*).

This book is based on a series of articles on testing machines and their applications, which were contributed to *Machinery* during the years 1931 and 1932, this being the fourth edition.

The contents are divided into twelve chapters and three sections, the latter comprising sections containing tables of properties of metals and alloys, a bibliography and an index. It is unfortunate that several pages of advertisements have been interleaved with the last two sections.

The first chapter deals with the various stress-strain relationships in tension, compression, shear, etc., and is reasonably comprehensive. Chapter II is headed "The Structure of Metals" and is altogether too brief to be of much use, and in any event is out of place in a book such as the present one.

The next three chapters deal with universal testing machines, tension and bending tests, and testing-machine accessories. Chapter VI describes a number of extensometers and recorders but makes no mention of the Lindley extensometer which is extensively used in this country.

Chapter VIII is concerned with hardness testing. A considerable portion is devoted to a little used hardness tester, viz., the Herbert Pendulum Hardness Tester, but no reference is made to some of the modern types of diamond hardness testers or to the latest model of the Vickers hardness testing machine. Neither is there a reference to B.S.I. No. 860 (Table of Approximate Comparison of Hardness Scales) which as early as 1939 was intended to supersede the conversion charts on page 168.

Impact testing is described in Chapter IX, whilst Chapter X is devoted to a consideration of repeated stress phenomena. Chapter XI covers the testing of wire and sheet metal, and the last chapter is devoted to some test phenomena and results.

It is disappointing to find creep testing so inadequately covered. Including the illustrations, only three pages are devoted to it and only one type of creep testing equipment is described. The determination of hardness at high temperatures, which was briefly referred to in the chapter on hardness testing, was also not given sufficient consideration, only four and a half lines being devoted to it.—J. FERDINAND KAYSER.

MELBOURNE UNIVERSITY. "*The Failure of Metals by Fatigue.*" Proceedings of a Symposium held in the University of Melbourne, Dec. 2nd–6th, 1946, under the aegis of the Faculty of Engineering. With a foreword by H. J. Gough, F.R.S. 8vo, pp. xvi + 505. Illustrated. Melbourne, 1947: Melbourne University Press; London: Cambridge University Press (42*s.*).

In his foreword Dr. Gough pays tribute to the University of Melbourne for the signal service rendered to a wide circle of scientists and engineers for the organization and publication of the comprehensive discussion on the subject of the fatigue of metals. Many of the papers, abstracts of which have appeared in the *Journal of The Iron and Steel Institute*, deal with problems of considerable interest and direct value to the designer and all concerned with the design, development or maintenance of machine parts subjected to cyclic stresses. The contents of the volume are as follows: The Failure of Metals by Fatigue, by J. Neill Greenwood; Metallography, Fatigue of Metals and Conventional Stress Analysis, by H. F. Moore; Theories of the Mechanism of Fatigue Failure, by W. Boas; Fatigue Problems Associated with Aircraft Materials, by H. Sutton; The Factors Contributing to Fatigue Failure in Aircraft, by C. W. George, S. F. Grover, and B. Chalmers; Repeated Loadings on Structures, by A. G. Pugsley; Structures Liable to Fatigue Failure and Some Considerations in Their Design, by L. R. Jackson and H. J. Grover; The Electrochemistry of Corrosion Fatigue, by U. R. Evans; The Detection of Fatigue Cracks by C. W. Orr; The Measurement of Dynamic Strain, by F. W. Hooton; Methods of Investigating the Fatigue Properties of Materials, by W. W. Johnstone; Determination of Stress Concentration Factors, by F. S. Shaw; Photo-Elasticity and Stress Concentration, by W. H. H. Gibson; Fatigue Tests on Four Welded H-Beams, by A. L. Percival and R. Weck; Residual Stresses, Their Measurement and Their Effects on Structural Parts, by G. Sachs; The Design of Cylindrical Shafts Subjected to Fluctuating Loading, by G. G. McDonald; Fatigue of Bolts and Studs, by J. G. Ritchie; The Fatigue of Welded Steel Tubing in Aircraft Structures, by C. J. Osborn; Notch Sensitivity of Metals, by M. S. Paterson; Composition and Physical Properties of Steel in Relation to Fatigue, by D. O. Morris; Conditions Leading to Fatigue Failure in Sleeve Bearings, by R. W. K. Honeycombe; Fatigue Problems in the Gas Turbine Aero Engine, by A. R. Edwards; The Prevention of Fatigue Failures in Metal Parts by Shot Peening, by J. G. Brookman and L. Kiddle; Failures of Railway Materials by Fatigue, by H. O'Neill; The Influence of Radial Pressure from a Press Fit on the Endurance Limit of Axles and Crank Pins, by G. W. C. Hirst; Fatigue Failure of Axles of Car and Wagon Railway Rolling Stock, by E. Connor; Types of Fatigue Failure in the Steel Industry, by W. O. Beale; Some Practical Aspects of Wire Fatigue in Aerial Telephone Lines Based on an Analysis of Wire Breakages, by D. O'Donnell and A. S. Bundle; The Vibration of Telephone Line Wires, by H. C. Levey and P. R. Brett; Fatigue Failures of Lead Sheathing of Telephone Cables, by S. D. Chivers.

NEW PUBLICATIONS

AZIENDA MINERALI METALLICI ITALIANI. "*Metalli non ferrosi e ferroleghe. Statistiche.*" Pp. 123. Rome, 1947: Ed. A.M.M.I.

BRITISH STANDARDS INSTITUTION, B.S. 15: 1948. "*Structural Steel.*" 8vo, pp. 18. London, 1948: The Institution. (Price 2*s.*).

BRITISH STANDARDS INSTITUTION. B.S. 449: 1948. "*The Use of Structural Steel in Building,*" 8vo, pp. 87. London, 1948: The Institution. (Price 6*s.*).

BRITISH STANDARDS INSTITUTION. B.S. 1121: Part 11: 1948. "*Methods for the Analysis of Steel.*" Part 11: "*Carbon in Steel and Low-Carbon Ferro-Chromium,*" 8vo, pp. 9. London, 1948: The Institution. (Price 1*s.*).

CHAMBRE SYNDICALE DES PRODUCTEURS D'ACIERS FINS ET SPÉCIAUX. "*Les Aciers Fins et Spéciaux Français.*" 8vo, pp. 301. Illustrated, Paris, 5 rue Paul-Cézanne.

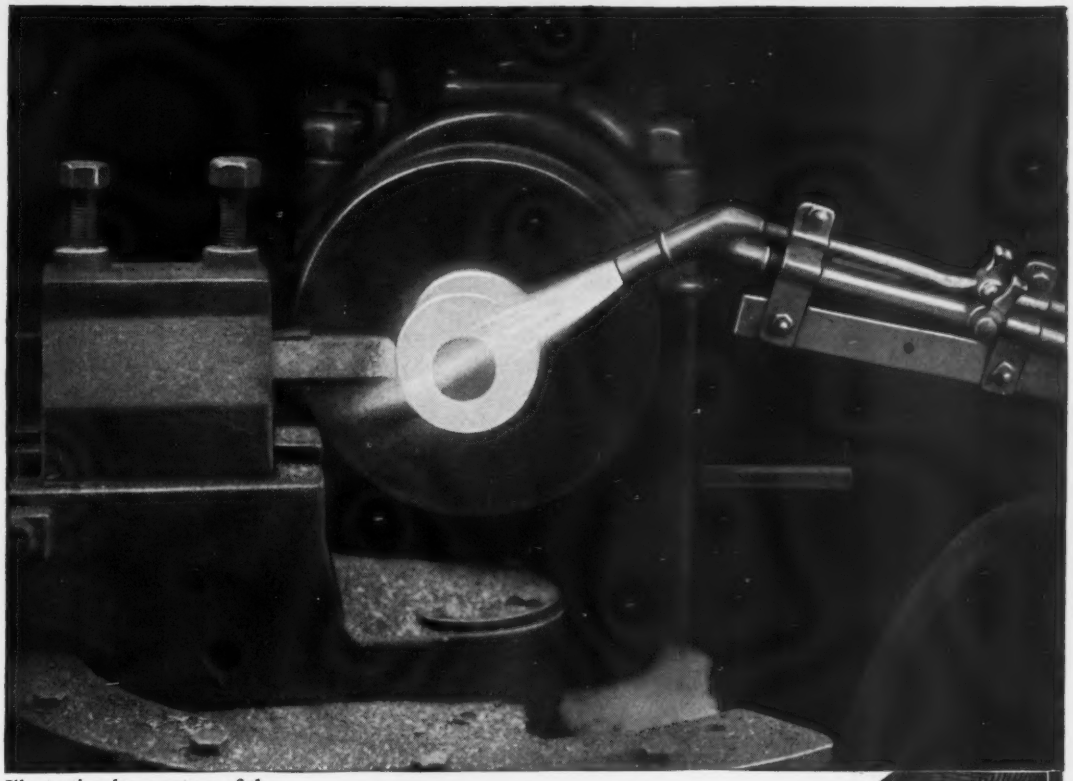
DINSDALE, C. "*Prevention of Iron and Steel Corrosion. Processes and Published Specifications.*" 8vo, pp. 88. London, 1948: The Louis Cassier Co., Ltd. (Price 5*s.*).

HENDRY, A. W. "*An Introduction to Photo-Elastic Analysis.*" 8vo, pp. viii + 152. Illustrated. London, 1948: Blackie and Son, Ltd. (Price 7*s.* 6*d.*).

WHITE, A. H. "*Engineering Materials.*" Second Edition. Pp. 697. New York: McGraw-Hill Book Co., Inc. (Price $6.00).

WOODWARD, W. E. "*Engineering Metallurgy.*" Pp. 178. London, 1948: Constable and Co. (Price 15*s.*).

YOUNG, R. S. "*Cobalt.*" Pp. 190. New York, 1948: Reinhold Publishing Corporation. (Price $5.00).



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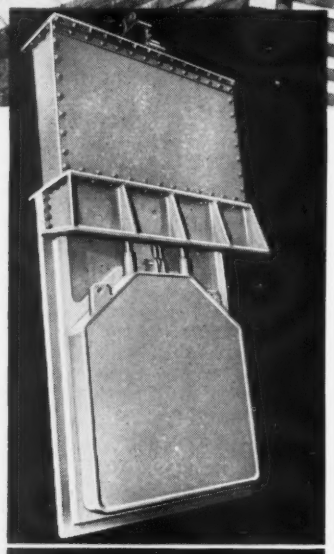

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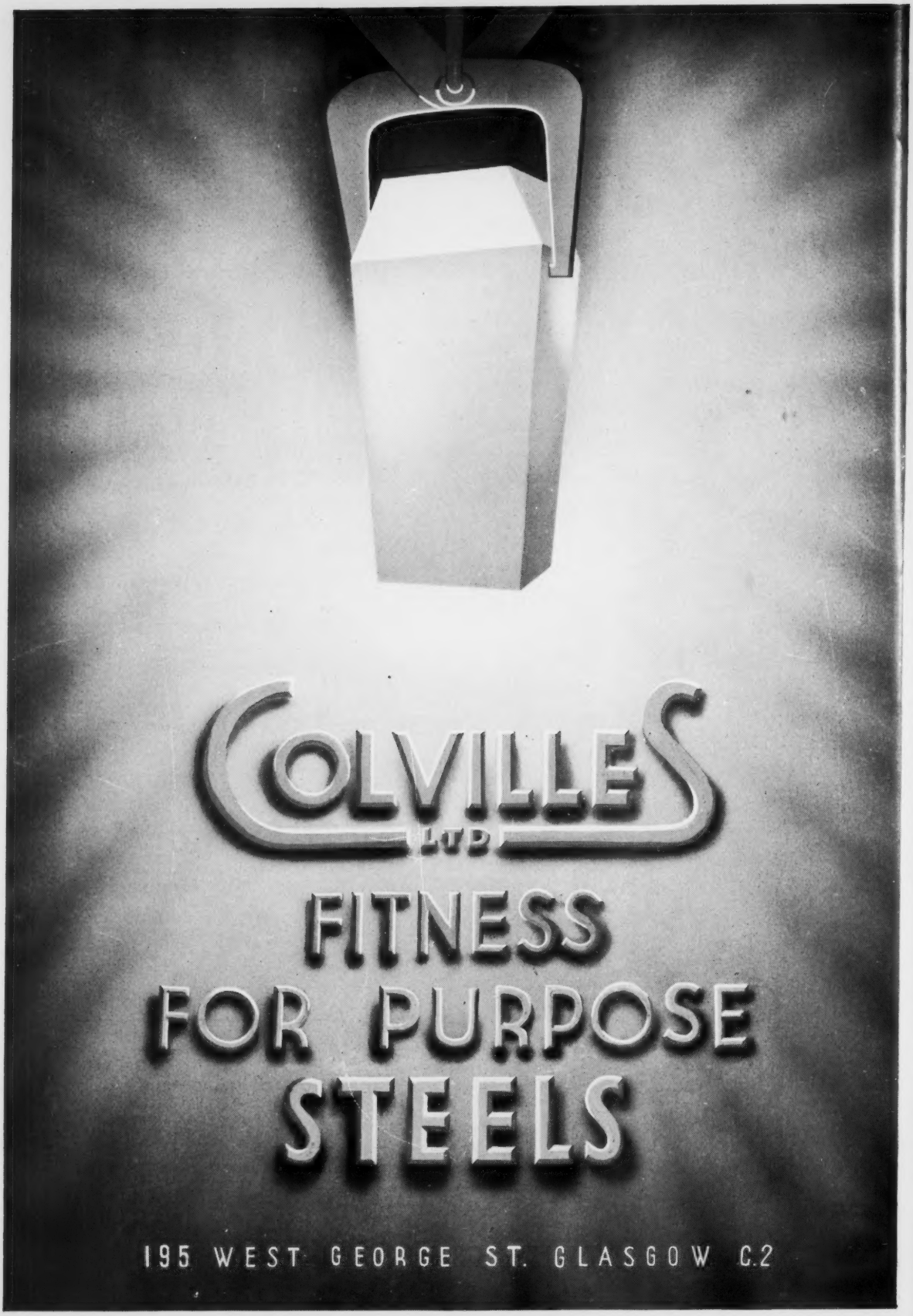
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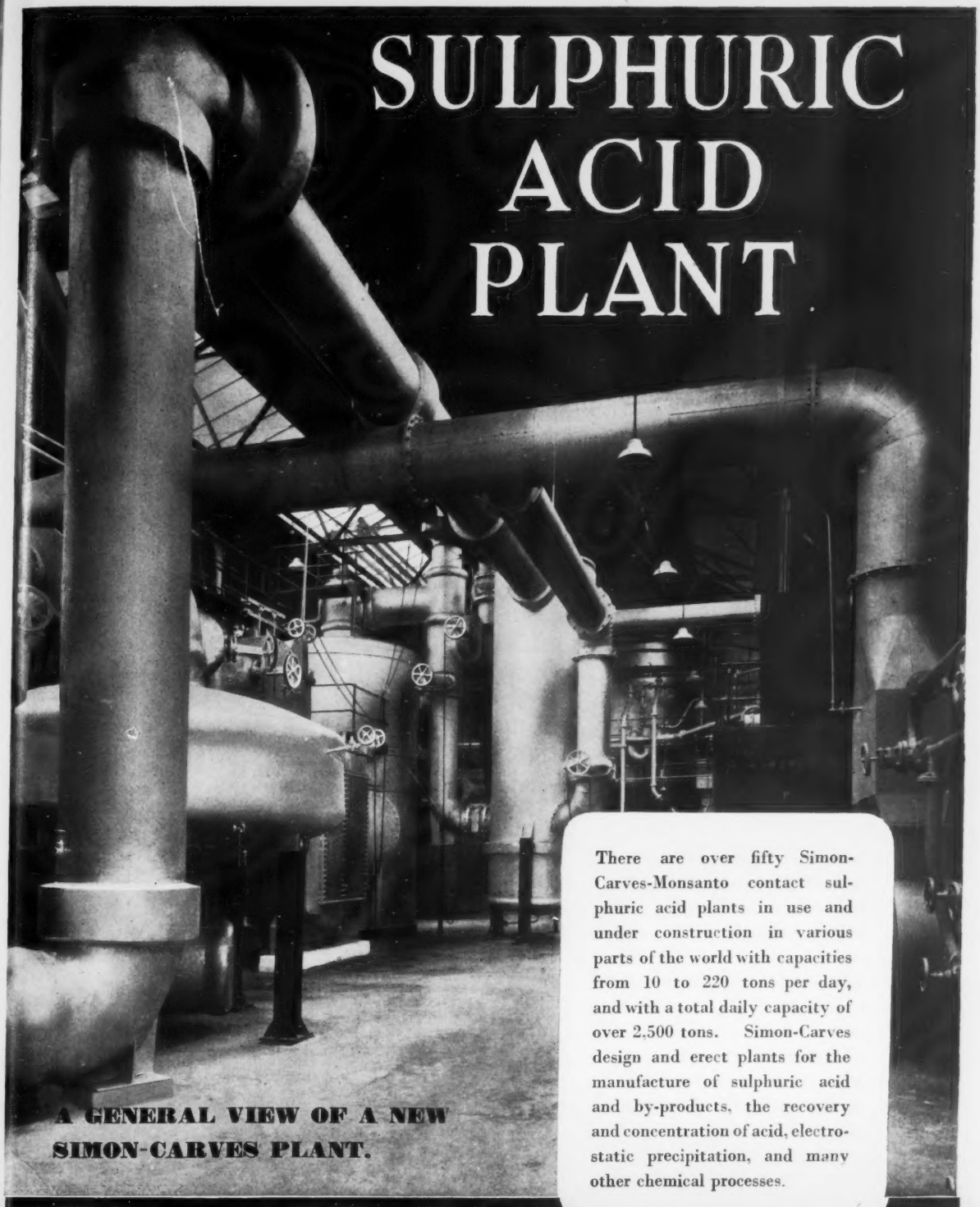

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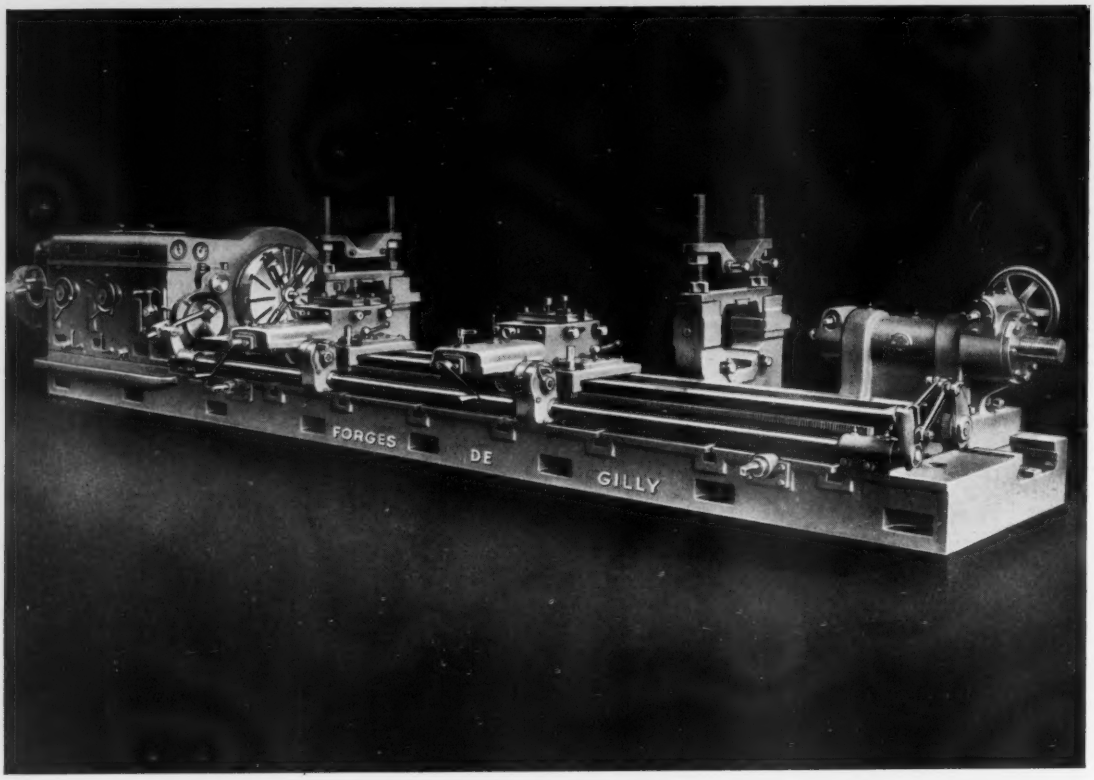

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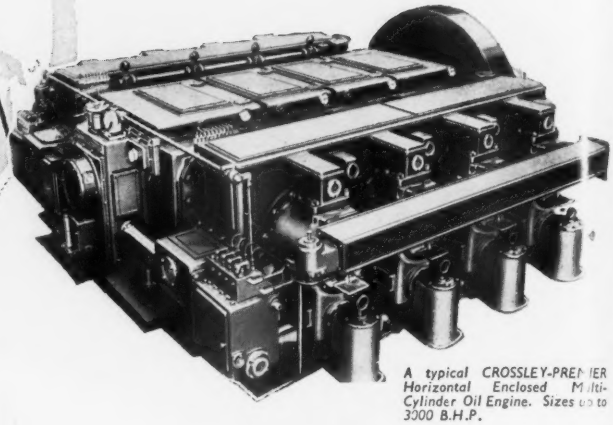

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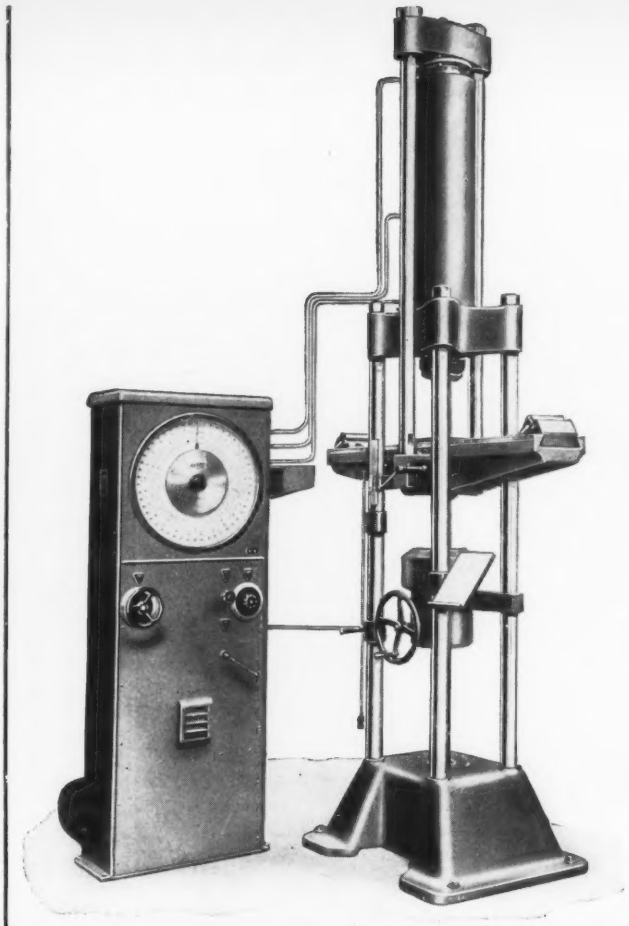

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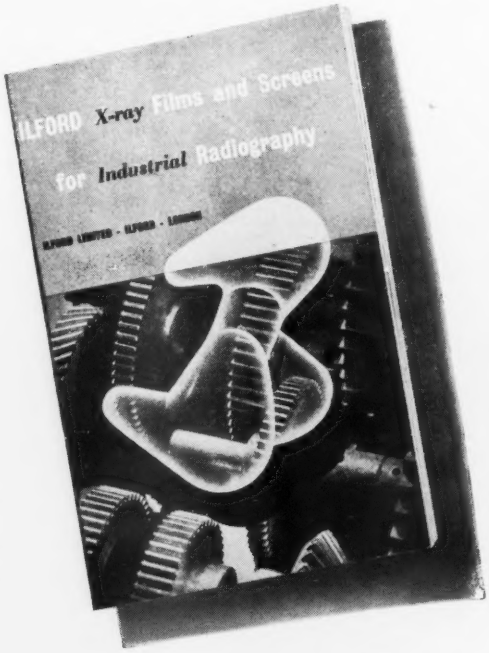

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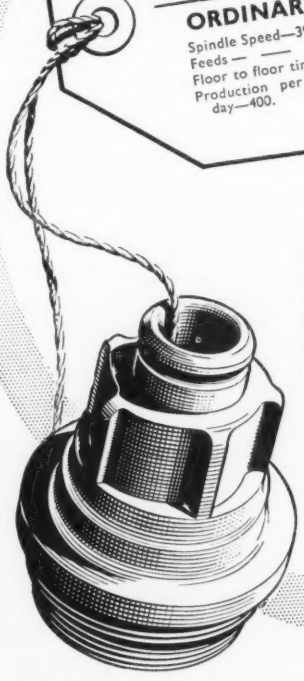

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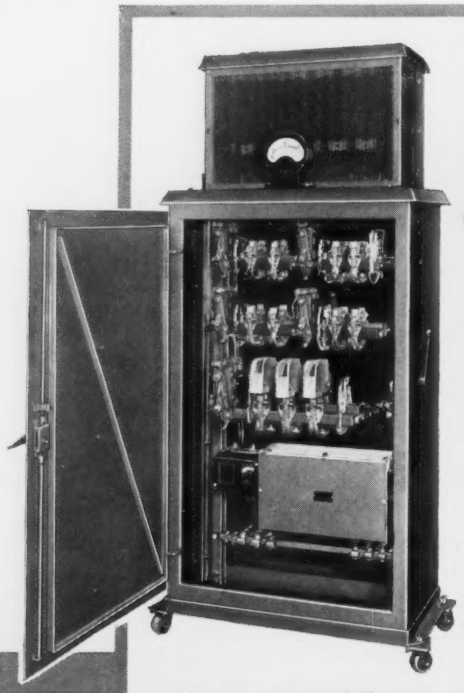

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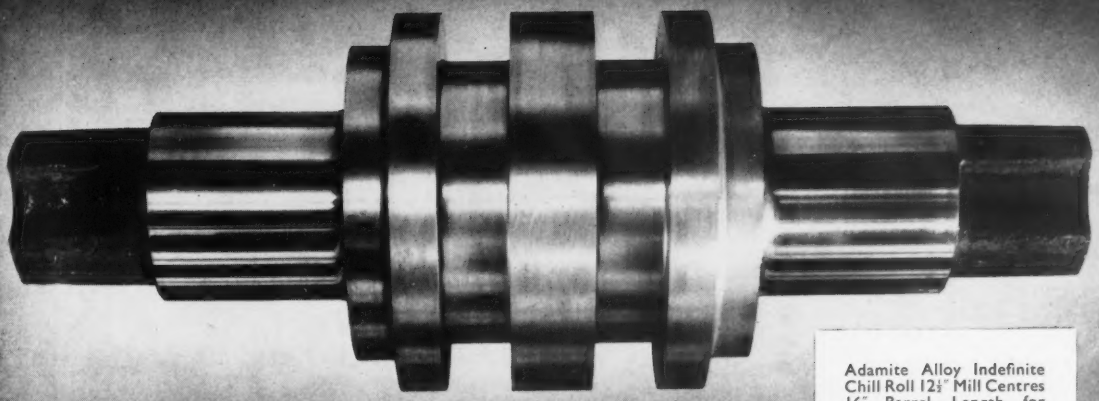

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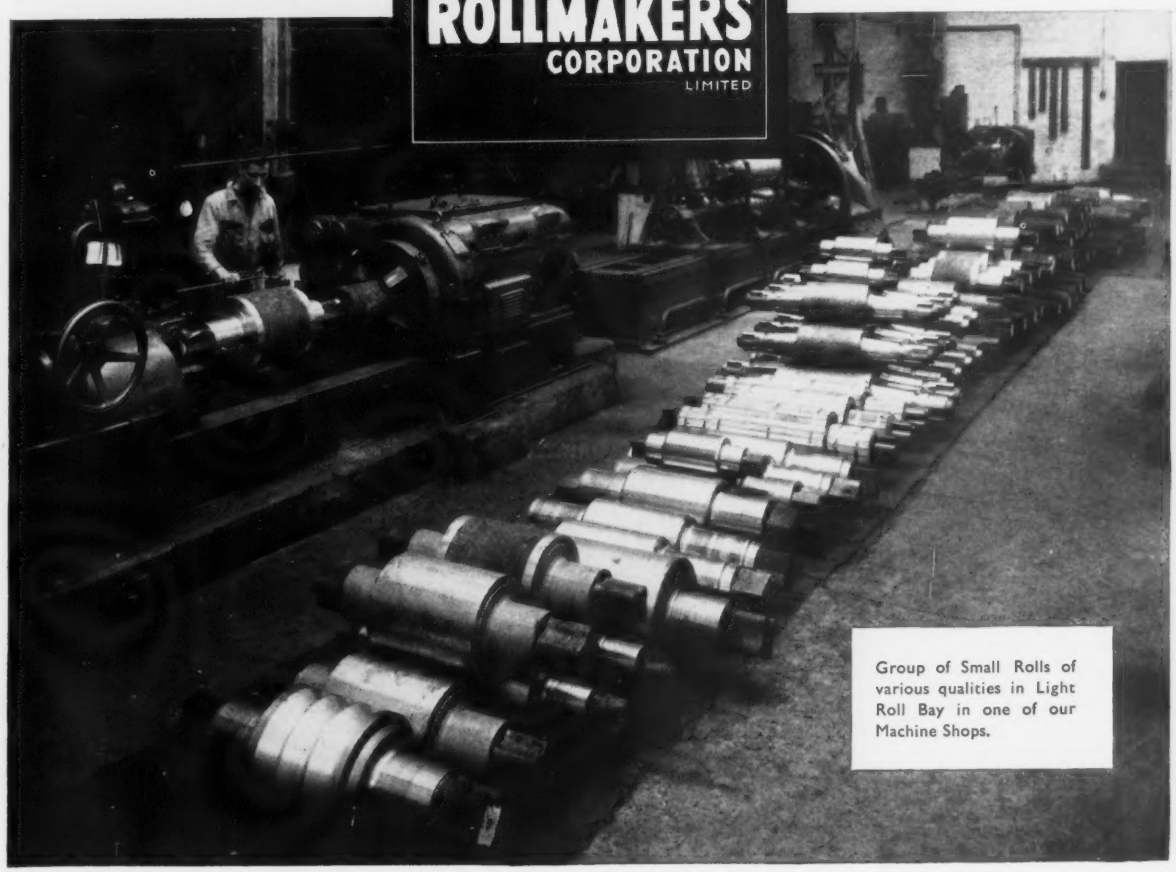

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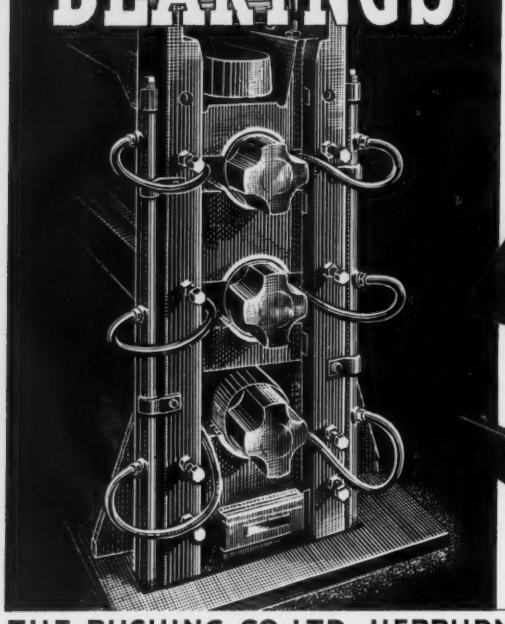

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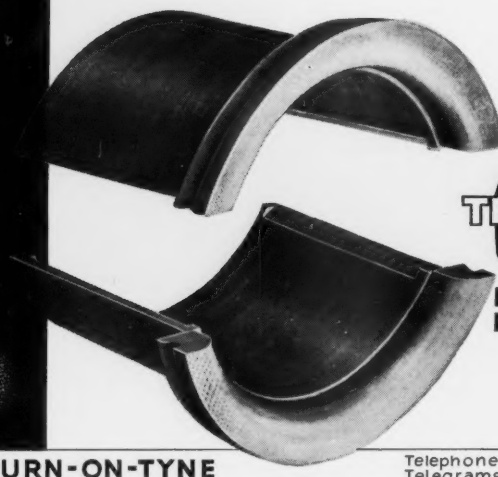

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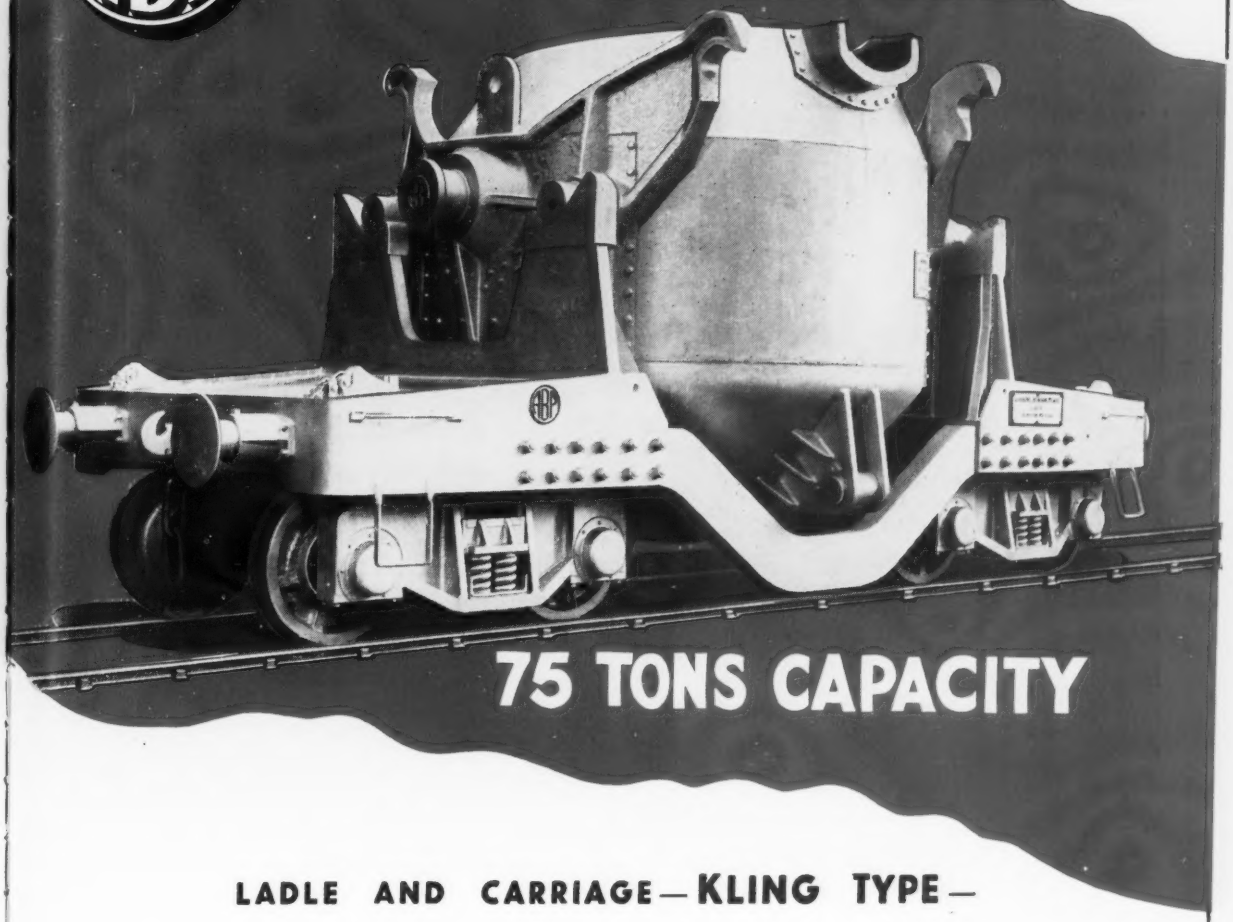

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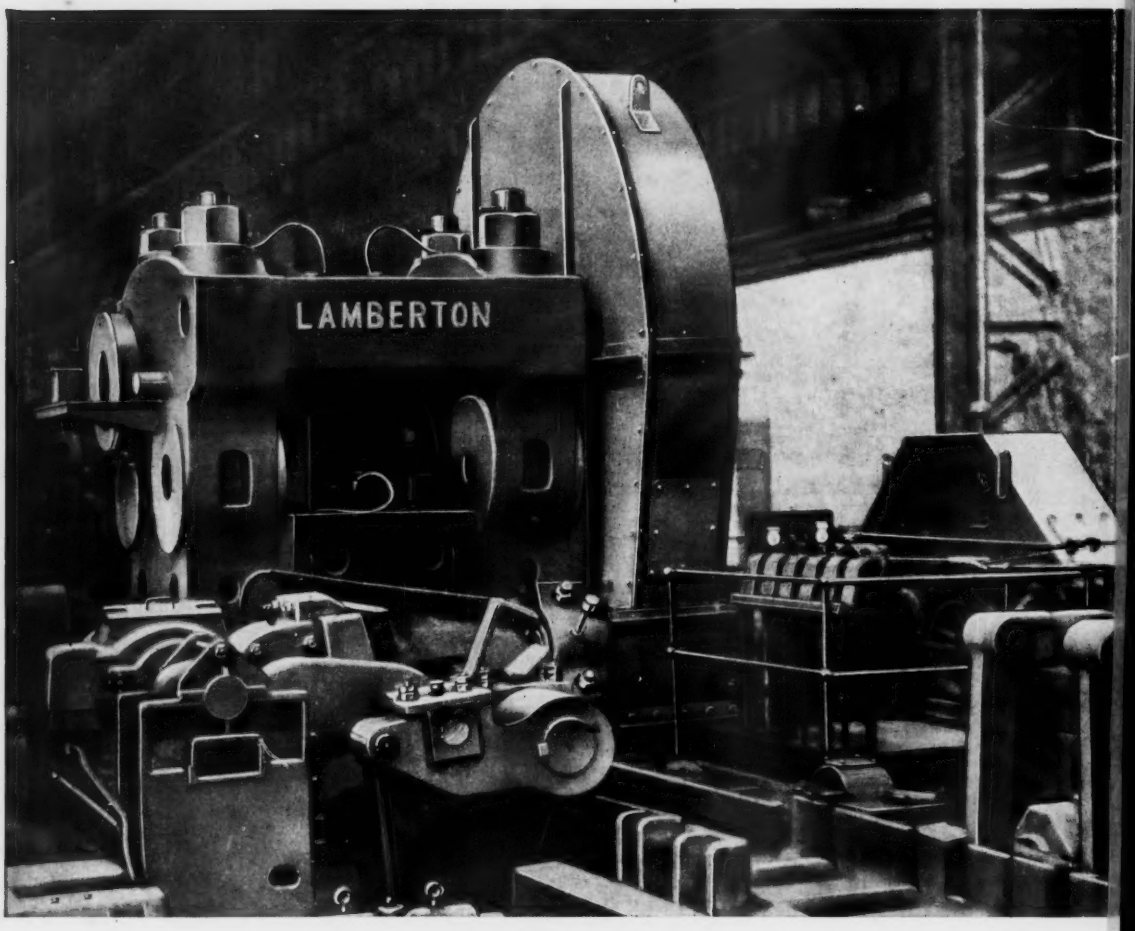

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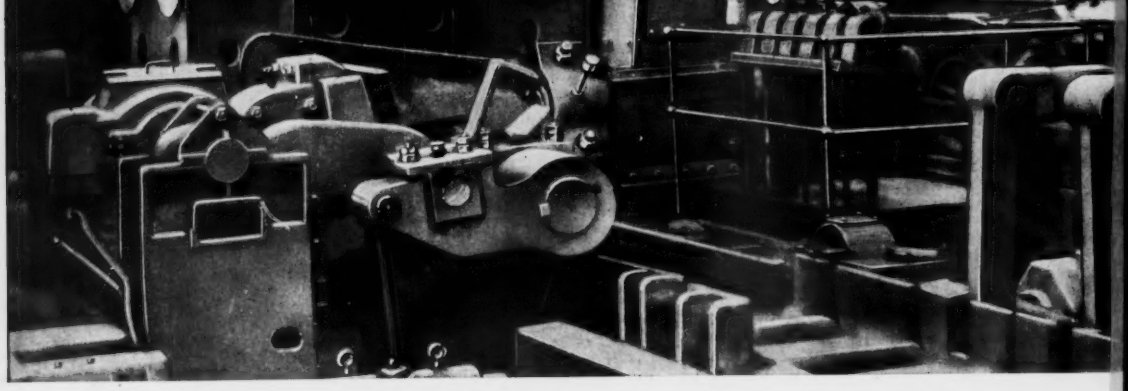

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